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(FEHER CYCLE) FOR SHIPBOARD APPLICATION

by

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AN INVESTIGATION OF THE SUPERCRITICAL CO2 CYCLE (FEHER CYCLE) FOR SHIPBOARD APPLICATION

by

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ABSTRACT

A thermodynamic analysis is conducted for the supercritical CO2 cycle used for a possible naval shipboard application. Four CO2 engines are analyzed to determine performance, efficiency, and fuel consumption of a 20,000 HP plant and then to measure the impact of the cycle components with the anticipated gains in performance in relation to the ship as a system.

The proposal of utilizing a supercritical carbon dioxide engine in a naval combatant is promising. It was concluded that there were significant increases in power or efficiency and they can be turned into worthwhile fuel savings, but the "true cost" to the ship system could conceivably offset any gains in fuel.

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CHAPTER 1

INTRODUCTION

1.1 Background

The rising price of fuel has been one of the important factors in the escalating costs of operating our naval ships in recent years. This higher cost of fuel combined with the shortage of domestic reserves has led to immediate cutbacks in ship operations in order to stay within operating budgets and to conserve petroleum reserves. Decreasing the rate of fuel consumption aboard ship is further complicated by the increasing demands for higher power generation from shipboard machinery systems recently found in the evolution of naval ship design. The most significant increases are in propulsion. Because the naval ship designer cannot solve the energy crisis, he is challenged with optimizing thermal efficiency and decreasing fuel consumption in the Navy's non-nuclear fleet.

The aircraft-derivative marinized gas turbine is projected as the primary non-nuclear main-propulsion power plant for U.S. Navy ships in the remaining quarter of this century. The development of the gas turbine into an efficient and versatile prime mover has resulted from recent component improvements which in turn were the

products of metallurgic, aerodynamic, and heat-transfer advances. The gas turbine is attractive because of its low weight per shaft horsepower, rapid response to power changes, lower manning levels, maintenance requirements, and modularity.

The advantages of the gas turbine are important to the designer, but its poor fuel-consumption rate is accented by increasing fuel costs and fuel shortages resulting from the energy crisis. Clearly, if the Navy is to solve its present dilemma and have a promising future, the specific fuel consumption of the gas turbine must be improved or a suitable replacement must be developed.

In 1967 Ernerst G. Feher (7)* proposed a thermodynamic power cycle which operates entirely above the critical pressure of the working fluid. The Supercritical Cycle is regenerative and the compression process is performed in the liquid phase. The result is high cycle efficiency. He proposed that an engine based on this cycle would be compact due to the high working fluid density.

Gokhshtein et.al. (10) discusses the design of CO_2 thermal power stations. He states that the power plants

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* Numbers in parenthesis refer to the references at the end of this thesis.

are compact and the heat exchangers are of acceptable dimensions. High efficiency is achieved.

An application of the supercritical cycle for space electric power is given in Reference (8). The study shows that the supercritical cycle system is significantly smaller and lighter than the conventional system used.

The ECAS study (6) concluded that efficiencies of 48 to 50 percent for a recompression supercritical cycle is achievable. Other than the high capital cost of major components, the cycle is promising for industrial applications.

The above discussions lead to the conclusion that a supercritical cycle could possibly provide a feasible solution to the poor fuel consumption and low system impact for naval propulsion plants. An investigation into the potential of applying a supercritical cycle to naval ships appears worthwhile.

1.2 Goal of Investigation

The reduction of fuel consumption for a particular piece of equipment is not a sufficient goal in machinery design for ship applications. If the method of fuel savings results in increased machinery weight or volume, or increased electrical load, the ship design may have to

grow even more than the machinery in order to maintain constant performance. Combining the goal of reducing fuel consumption for machinery and the goal of minimizing the ship design may not be compatible if the impact of the system adversely affects the total-ship system.

The goal of this study is to conduct a thermodynamic analysis of the supercritical cycle in order to investigate the performance, efficiency, and fuel consumption of a 20,000 HP plant and then to measure the impact of the cycle components with the anticipated gains in performance in relation to the ship as a system.

1.3 Summary of Approach

The two major goals of this study discussed in section 1.2 lend themselves to three distinct areas of investigation. First, the thermodynamic analysis of the basic Feher cycle and the Recompression cycle (a variation of the basic cycle) will be undertaken to determine cycle efficiency, and specific fuel consumption under design conditions and to predict its off design performance. The second area consists of sizing the major components. The third area of study measures the impact of the advantages in specific fuel consumption and component sizes on a total ship-system.

The analysis of the thermodynamic cycles are found in Chapter 2. Chapter 3 discusses component sizes. Total ship impact is considered in Chapter 4. In Chapter 5, findings, conclusions, and recommendations are presented.

CHAPTER 2

THERMODYNAMIC ANALYSIS

2.1 Introduction

The purpose of conducting the thermodynamic analysis is to calculate the performance of the Feher Basic Cycle and the Recompression Cycle (a variation of the basic cycle) under design conditions and to predict its off design performance. Hence, the specific fuel consumption is determined for all power levels.

This study limits the thermodynamic analysis to the cycles utilized in References (7) and (6). No parametric analysis is performed to determine the best range of operation as it is assumed that the base cases presented in the literature represent a good starting point for the scope of this work.

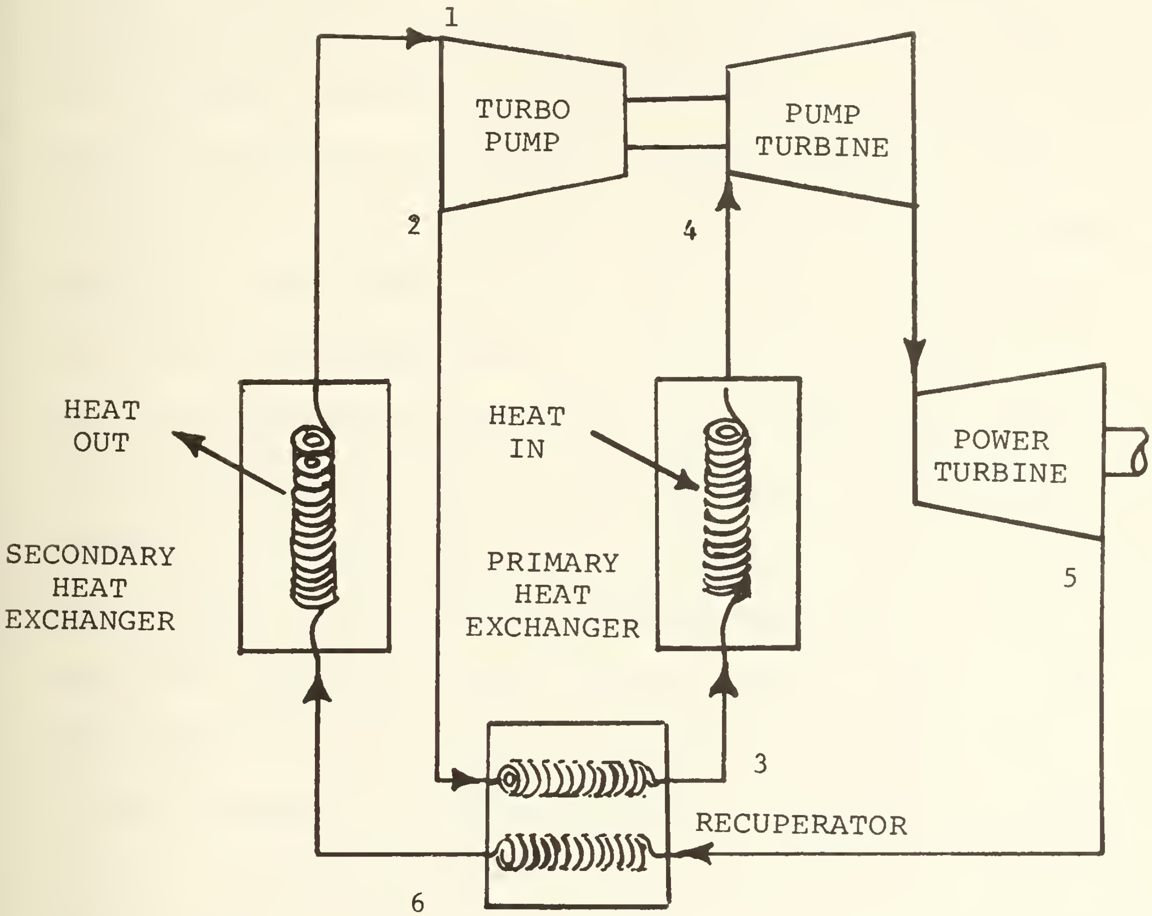
2.2 Feher Basic Cycle

2.2.1 Cycle Description

The basic cycle consists of five major components: pump, primary heat exchanger, turbine, recuperator, and secondary heat exchanger. For these major components, cycle pressure drops, temperature and enthalpy changes are shown in Figure 1. The pressure ranges from 1700 psia at pump inlet to 4200 psia at pump exit. The

FIGURE 1

COMPONENTS OF BASIC CYCLE



	TEMPERATURE	ENTHALPY	PRESSURE
1	80°F	240.6	1700
2	113.6	250.7	4200
3	950.5	551.48	4150
4	1300	657.28	4100
5	1099.1	600.02	1800
6	143.6	299.24	1720

turbine pressure ratio is 2.27. Other pressure drops are distributed throughout the system as shown.

The temperature entropy diagram shown in Figure 2 represents the cycle's operation. From state 1 to 2 the working fluid is compressed isentropically from P1 to P2. At constant pressure P2, heat is added from state 2 to 4. Work is achieved by expanding isentropically between state 4 and 5 from P2 to P1. Heat is removed at constant pressure from state 5 to 6. An attractive feature of the cycle is regeneration. A portion of the heat extracted between state 5 and 6 is transferred back to the fluid between state 2 and 3, thus increasing the enthalpy on the high side of the cycle. Heat input from an external heat source occurs between state 3 and 4 and net heat rejection occurs between state 6 and 1. The net work of the cycle is the difference between the turbine expansion (state 4 to 5) and compression (state 1 to 2). Thermal efficiency is calculated as the net work out divided by the net heat input.

The performance of the system's components are important influences on overall efficiency. The pump will be assumed to have an efficiency of 85%. The turbine efficiency is set at 90%. Feher (7,9) discusses the effect of temperature differences at recuperator

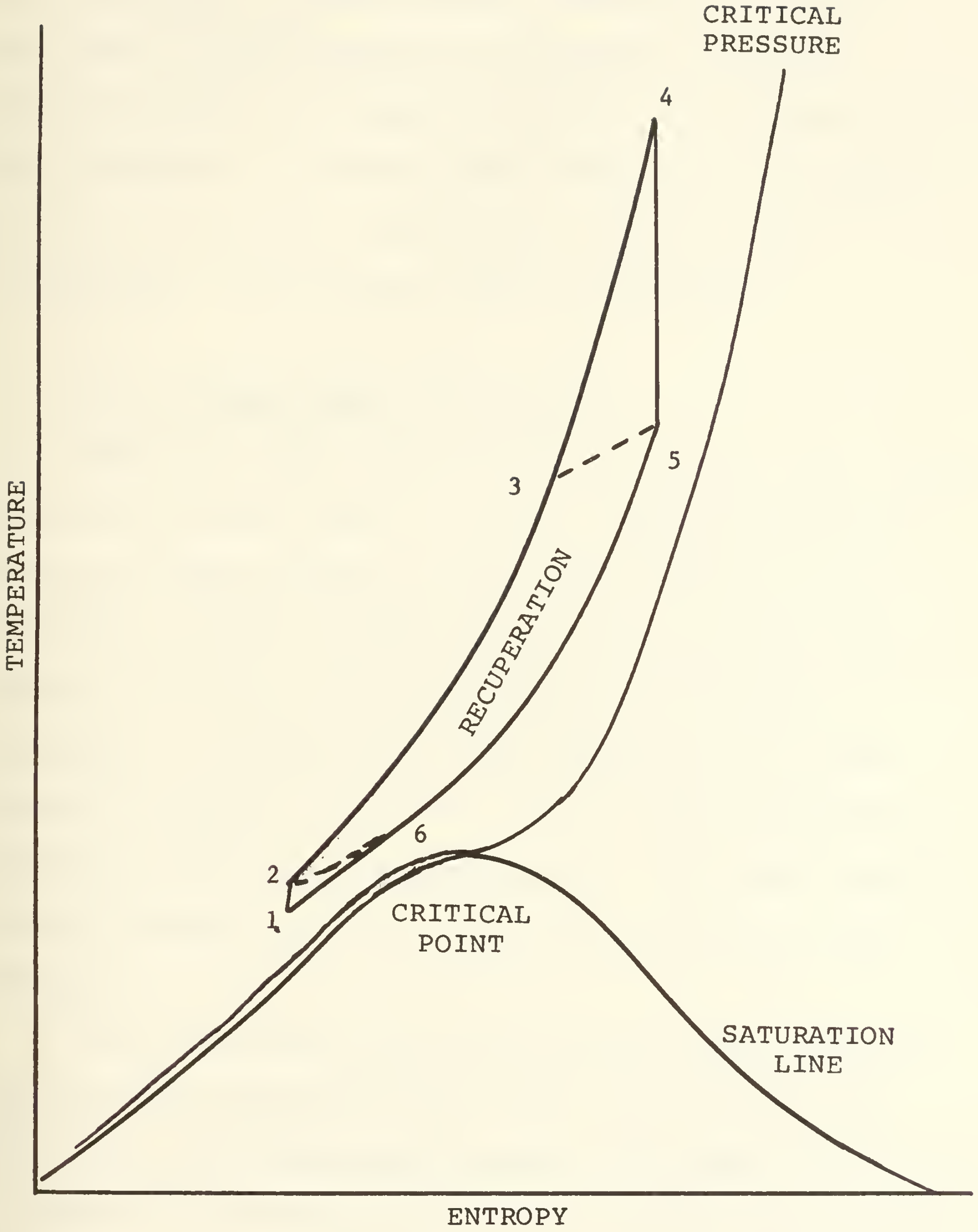


FIGURE 2. TEMPERATURE-ENTROPY DIAGRAM (FEHER CYCLE)

pinch points (ΔT) on cycle efficiency and recuperator effectiveness. As the minimum temperature at pinch decreases, effectiveness and efficiency increases. However, weight and length increases. To minimize weight and volume and to achieve good efficiency, a minimum ΔT of 30° is selected. The pump and turbine inlet temperatures are 80°F and 1300°F respectively.

2.2.2 Basic Cycle Performance

Feher (7) states that the supercritical cycle can be operated with any fluid. Initial investigations were based on carbon dioxide as the working fluid for four reasons: (1) its critical pressure is one third that of water, (2) it is known to be stable in the region of interest, (3) literature on the properties of carbon dioxide is readily available, and (4) carbon dioxide is abundant, non-toxic, and inexpensive. For these reasons, carbon dioxide is used as the working fluid for this analysis.

The calculations for the cycle are based upon the property data of supercritical CO2 calculated by the NASA GASP (Gas Properties) Program. The data is available in tabular and computerized format. Additional information on the program can be obtained from Reference (12).

Application of the first law to the cycle numbered in Figure 2 shows the pump work, turbine work, net work, net heat input, and cycle efficiency to be given by Equations [2.1] - [2.5].

$$\dot{W}_p = \dot{m}(h_{02} - h_{01}) \tag{2.1}$$

$$\dot{W}_T = \dot{m}(h_{04} - h_{05}) \tag{2.2}$$

$$\dot{W}_{net} = \dot{W}_T - \dot{W}_p = \dot{m}(h_{04} - h_{05}) - \dot{m}(h_{02} - h_{01}) \tag{2.3}$$

$$\dot{Q}_{in} = \dot{m}(h_{04} - h_{03}) \tag{2.4}$$

$$\eta_{cycle} = \frac{\dot{W}_{net}}{\dot{Q}_{in}} = \frac{(h_{04} - h_{05}) - (h_{02} - h_{01})}{(h_{04} - h_{03})} \tag{2.5}$$

Mechanical efficiencies are taken to be 98%. Two percent (2%) of the net work is considered sufficient to account for any parasitic losses throughout the system. Equation [2.5] now becomes:

$$\eta_{cycle} = \frac{(.98)(.98)(h_{04} - h_{05}) - (h_{02} - h_{01})/.98}{(h_{04} - h_{03})} \tag{2.6}$$

From Equations [2.1] - [2.4] and [2.6] the thermal

efficiency of the basic engine is calculated to be 42.4%. When the efficiency of the combustor is considered, the system efficiency may be determined. A combustor efficiency, η_H, of 88% is used. Therefore, from Equation [2.6], the system efficiency becomes 37.3%.

Specific fuel consumption (SFC), mass flow of fuel per shaft horsepower, is determined by Equation [2.7],

$$SFC = \frac{\text{mass flow of fuel}}{\text{shaft horsepower}} = \frac{\dot{m}_f}{SHP} \qquad [2.7]$$

where the mass flow of fuel is defined by Equation [2.8],

$$\begin{aligned} \text{mass flow of fuel} &= \frac{\text{heat input}}{\text{combustor efficiency} \cdot \text{lower htg. value}} \\ &= \frac{\dot{m}(h_{04} - h_{03})}{\eta_H \times LHV} \qquad [2.8] \end{aligned}$$

and the Lower Heating Value (LHV) of the fuel is taken to be 18,400 BTU's/Lb Heating Value. The SFC at this LHV is .37 Lbm fuel per shaft horsepower HR.

2.2.3 Off-Design Performance

One inherent disadvantage of the basic engine for naval applications is the danger of not achieving the low temperatures required for condensing. As naval ships

must operate in any part of the world, cooling water temperature could often exceed 80°F. Figure 3 illustrates the sensitivity of pump inlet temperature on cycle efficiency and specific power output. Figure 4 depicts changes in cycle efficiency and specific power output if turbine inlet temperature is not obtained. If turbine pressure ratio is reduced, the cycle efficiency and specific power reduces accordingly as shown in Figure 5.

Operational profiles of naval ships dictate engine operation other than at full power. Thus, it is important to predict the cycle's performance. Changes in power level is achieved by varying the pressure ratio and holding flow and turbine inlet temperature constant. Figure 6 illustrates the specific fuel consumption over wide power ranges for this mode of part-load operation.

2.3 Recompression Cycle

2.3.1 Cycle Description

The Recompression Cycle is a variation of the basic cycle design. The basic cycle consists of seven major components: pump, primary heat exchanger, secondary heat exchanger, compressor, high temperature recuperator, low temperature recuperator, and turbine. These major

Pump Inlet Temperature vs. Efficiency and Specific Power
(Basic Engine)

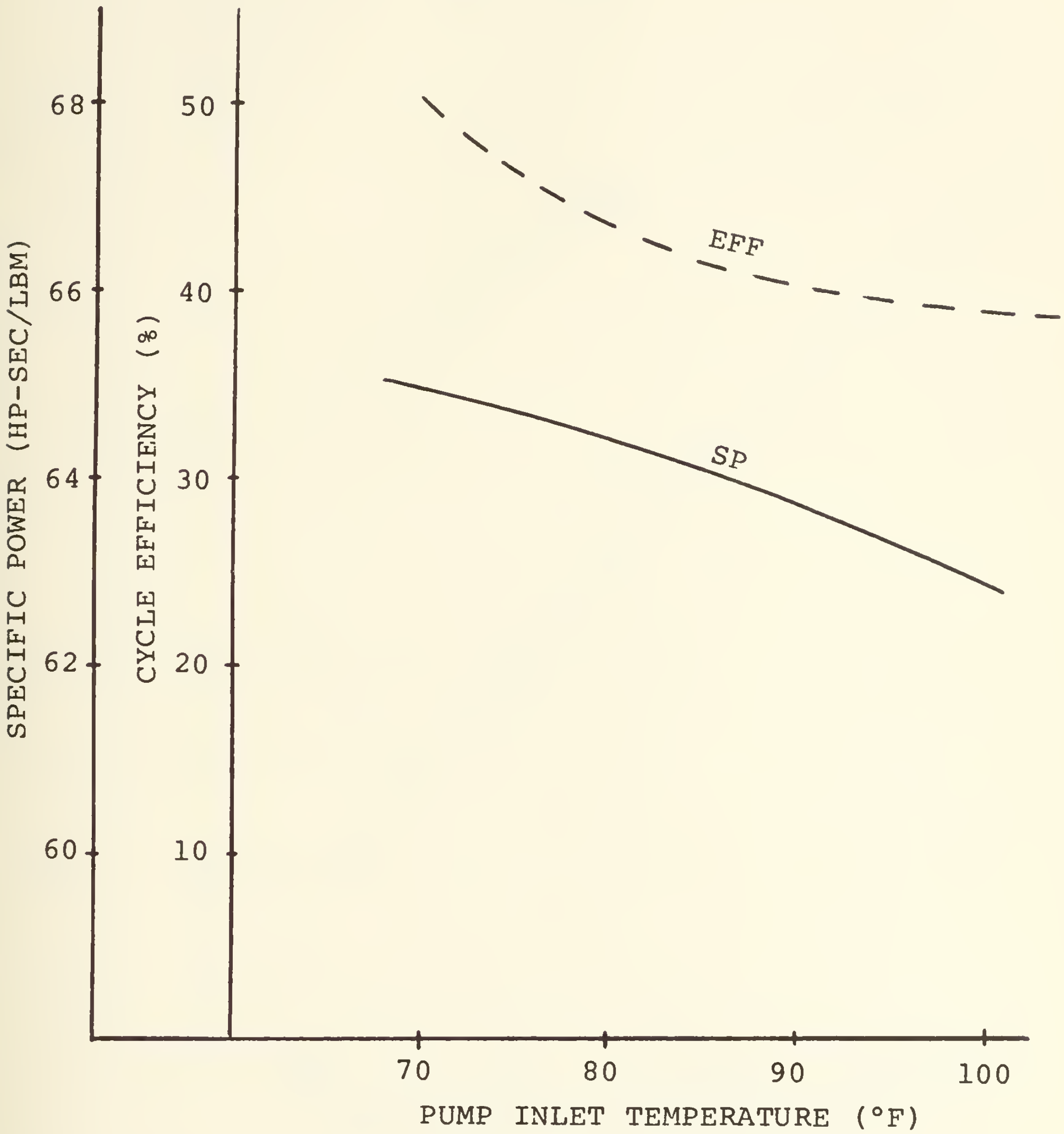


FIGURE 3

Turbine Inlet Temperature vs. Cycle Efficiency
and Specific Power

(Basic Cycle)

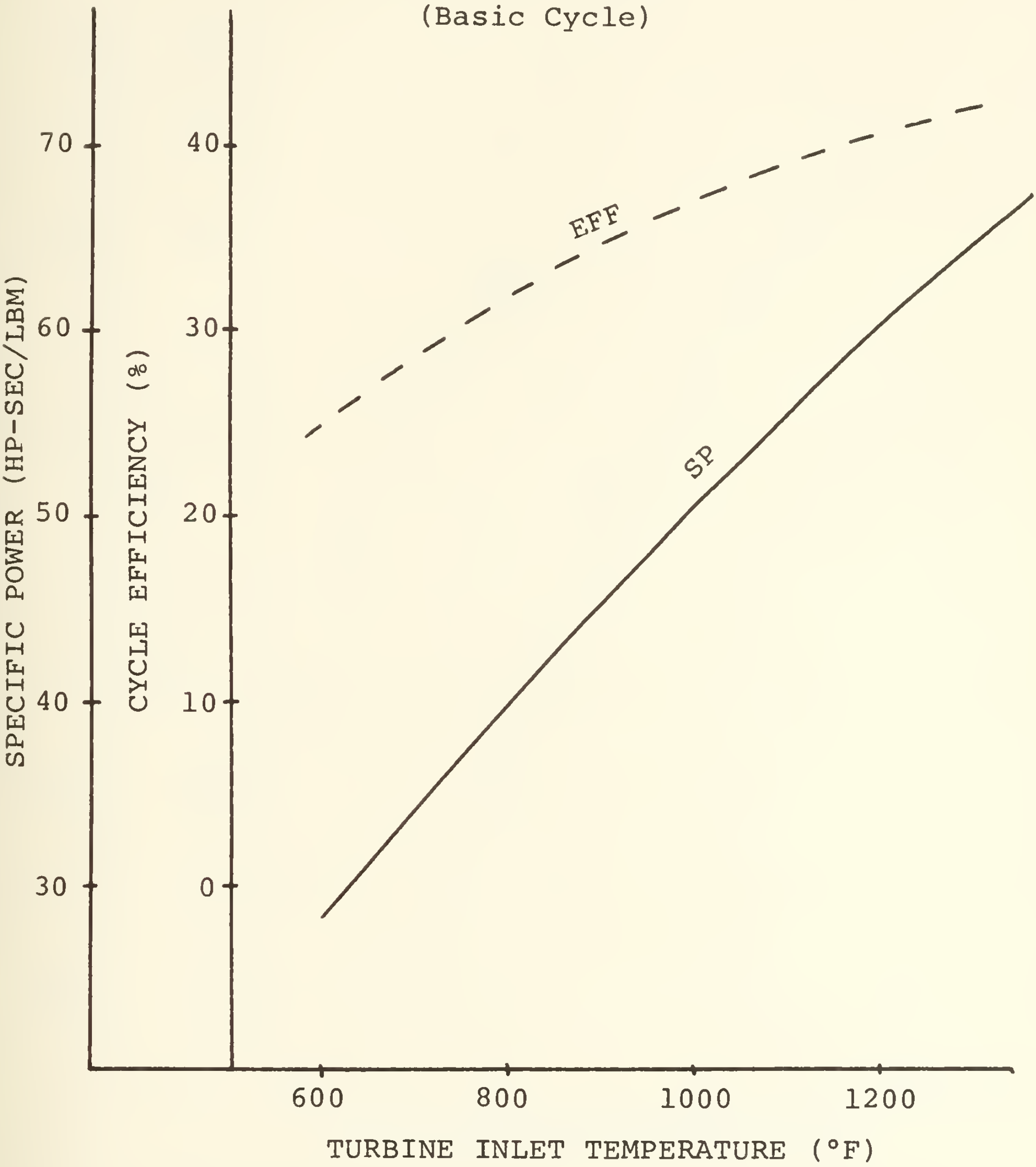


FIGURE 4

Turbine Pressure Ratio vs. Cycle Efficiency
and Specific Power

(Basic Cycle)

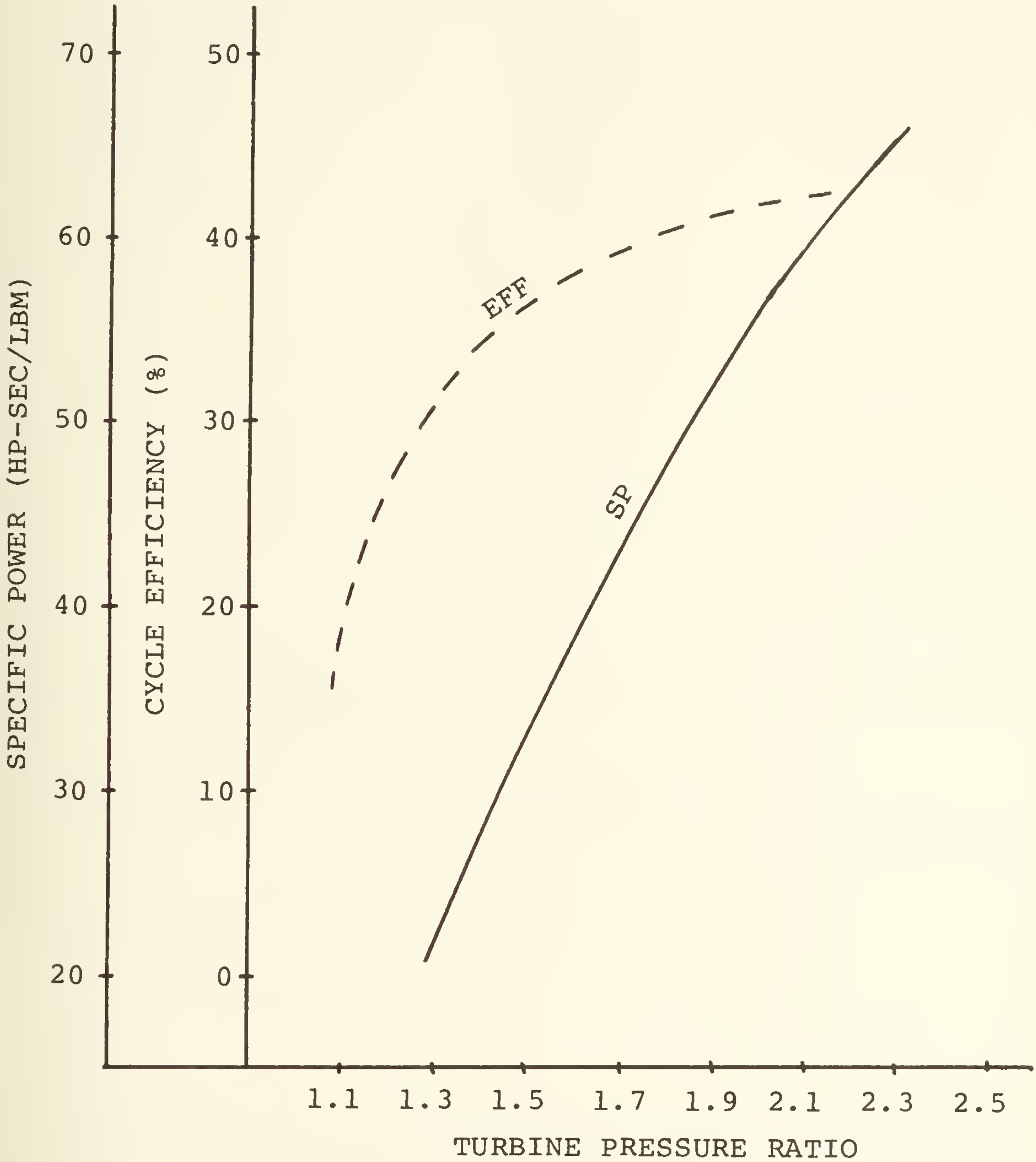


FIGURE 5

Percentage of Power vs. Specific Fuel Consumption
(Basic Cycle)

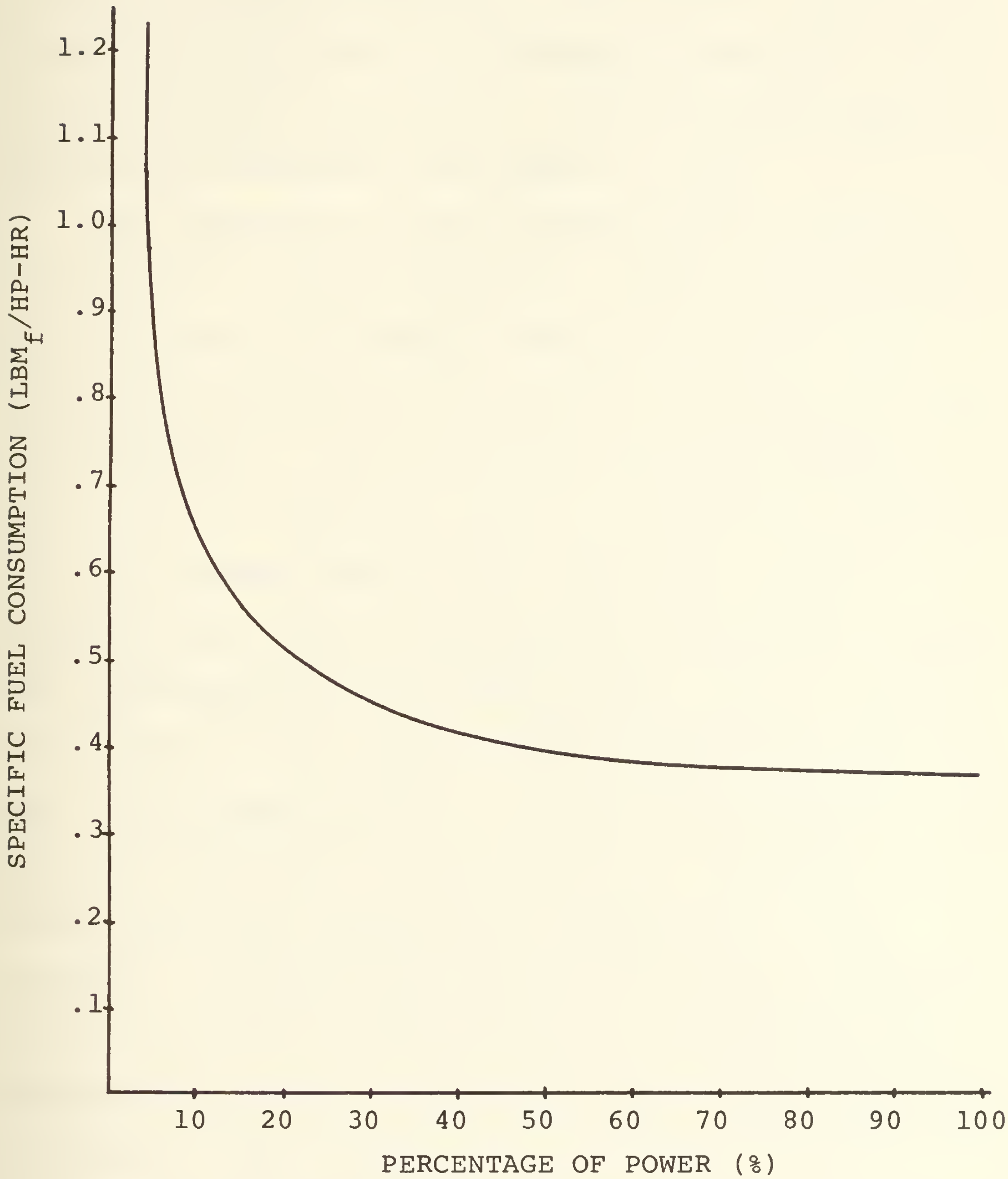


FIGURE 6

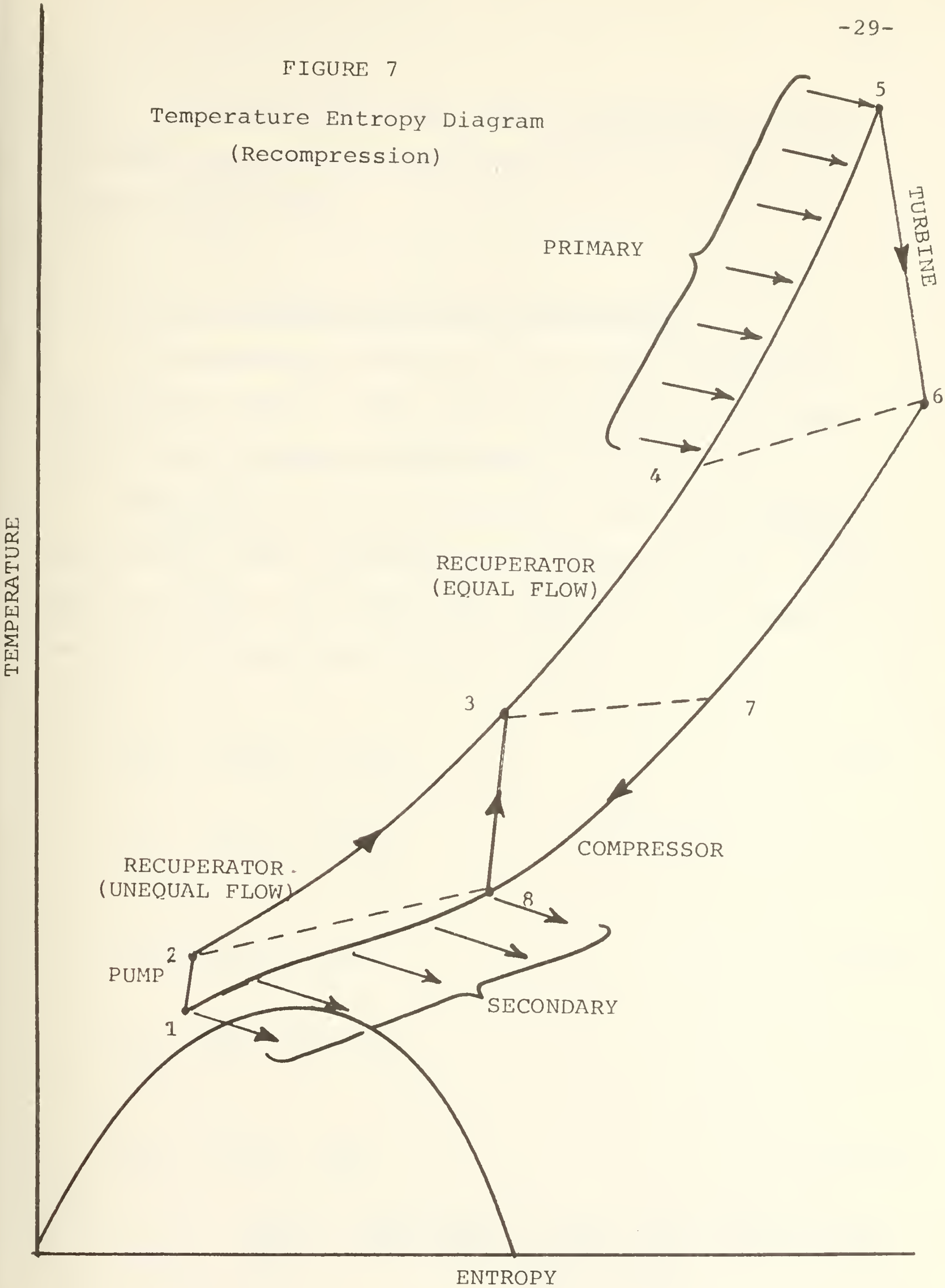
components, cycle pressure drops, temperature and enthalpy changes are shown in Figure 8. The pressure ranges from 1330 psia at pump inlet to 3840 psia at pump exit. The turbine pressure ratio is 2.7. Other pressure drops are distributed throughout the system as shown.

The temperature entropy diagram shown in Figure 7 represents the cycle's operation. As the recompression cycle operates in a similar manner to the basic cycle described in section 2.2.1, only the differences will be discussed here. Part of the heat extracted between state 6 and 7 and state 7 and 8 is transferred back to the fluid between state 2 and 3 and state 3 and 4 respectively. The low-pressure flow is split as it exits the low-temperature recuperator (state 7 to 8). Thirty (30) percent of the flow is compressed between state 8 and 3; the remaining portion of the flow continues between state 8 and 1 (heat rejection). Reference (6) states that this configuration provides for a flow mismatch in the low-temperature recuperator and results in the achievement of more effective regeneration and subsequently higher efficiencies with a slight reduction in specific power output.

The pump and turbine are assumed to have efficiencies of 90%. The compressor efficiency is set at

FIGURE 7

Temperature Entropy Diagram
(Recompression)



87%. The minimum ΔT in the cycle is selected at 20°F. The pump and turbine inlet temperatures are 80°F and 1350°F respectively.

2.3.2 Recompression Cycle Performance

As discussed in section 2.2.2, carbon dioxide is the working fluid. Also, cycle calculations are based on the GASP Program as discussed in section 2.2.2.

Application of the first law to the cycle numbered in Figure 7 shows the pump work, compressor work, turbine work, net work, net heat input, and cycle efficiency to be given by Equations [2.9] to [2.14].

$$\dot{W}_p = .7\dot{m}(h_{02} - h_{01}) \qquad [2.9]$$

$$\dot{W}_c = .3\dot{m}(h_{03} - h_{08}) \qquad [2.10]$$

$$\dot{W}_T = \dot{m}(h_{05} - h_{06}) \qquad [2.11]$$

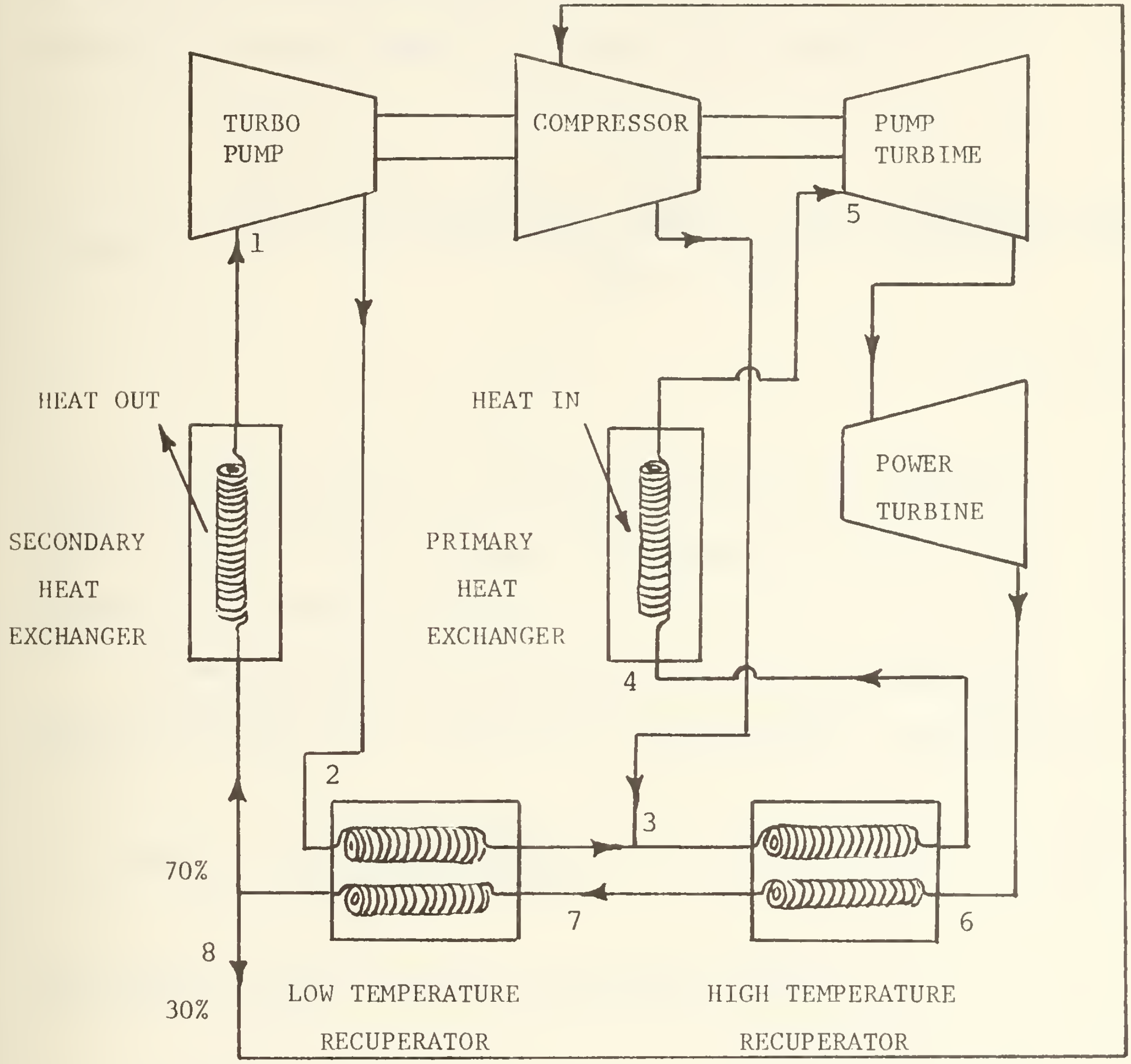
$$\dot{W}_{net} = \dot{W}_T - \dot{W}_p - \dot{W}_c \qquad [2.12]$$

$$\dot{Q}_{in} = \dot{m}(h_{05} - h_{04}) \qquad [2.13]$$

$$\eta_{cycle} = \frac{\dot{W}_{net}}{\dot{Q}_{in}} = \frac{(h_{05} - h_{06}) - .7(h_{02} - h_{01}) - .3(h_{03} - h_{04})}{(h_{05} - h_{04})} \qquad [2.14]$$

FIGURE 8

COMPONENTS OF RECOMPRESSION ENGINE



	TEMPERATURE	ENTHALPY	PRESSURE
1	80	243.57	1330
2	118	253.56	3840
3	301.2	343.77	3826
4	992.4	564.30	3810
5	1350	672.87	3780
6	1106.7	603.10	1400
7	321.2	382.58	1370
8	142.5	319.41	1340

Mechanical efficiencies are taken to be 98% and 2% for parasitic loss. Equation [2.14] now becomes:

$$\eta_{cycle} = \frac{(.98)(.98)(h_{05} - h_{06}) - \frac{.7}{.98}(h_{02} - h_{01}) - \frac{.3}{.98}(h_{03} - h_{08})}{(h_{05} - h_{04})}$$

.....[2.15]

From Equations [2.9] - [2.13] and [2.15] the thermal efficiency of the recompression engine is 48.6%. The system efficiency is 42.8%.

As determined from Equation [2.16], the specific fuel is found to be .32 Lbm of fuel/SHP-HR. The LHV is

$$S.F.C. = \frac{\dot{m}(h_{05} - h_{04})}{\eta_H \times LHV \times SHP} \qquad [2.16]$$

the same as that used for the basic cycle.

2.3.3 Off-Design Performance

As indicated on Figure 9, cycle efficiency and specific power output decrease as pump inlet temperature increases. Figure 10 illustrates the effect of reduced turbine inlet temperature on cycle efficiency and specific power output. The variation in turbine pressure ratio

Pump Inlet Temperature vs. Cycle Efficiency
and Specific Power

(Recompression Cycle)

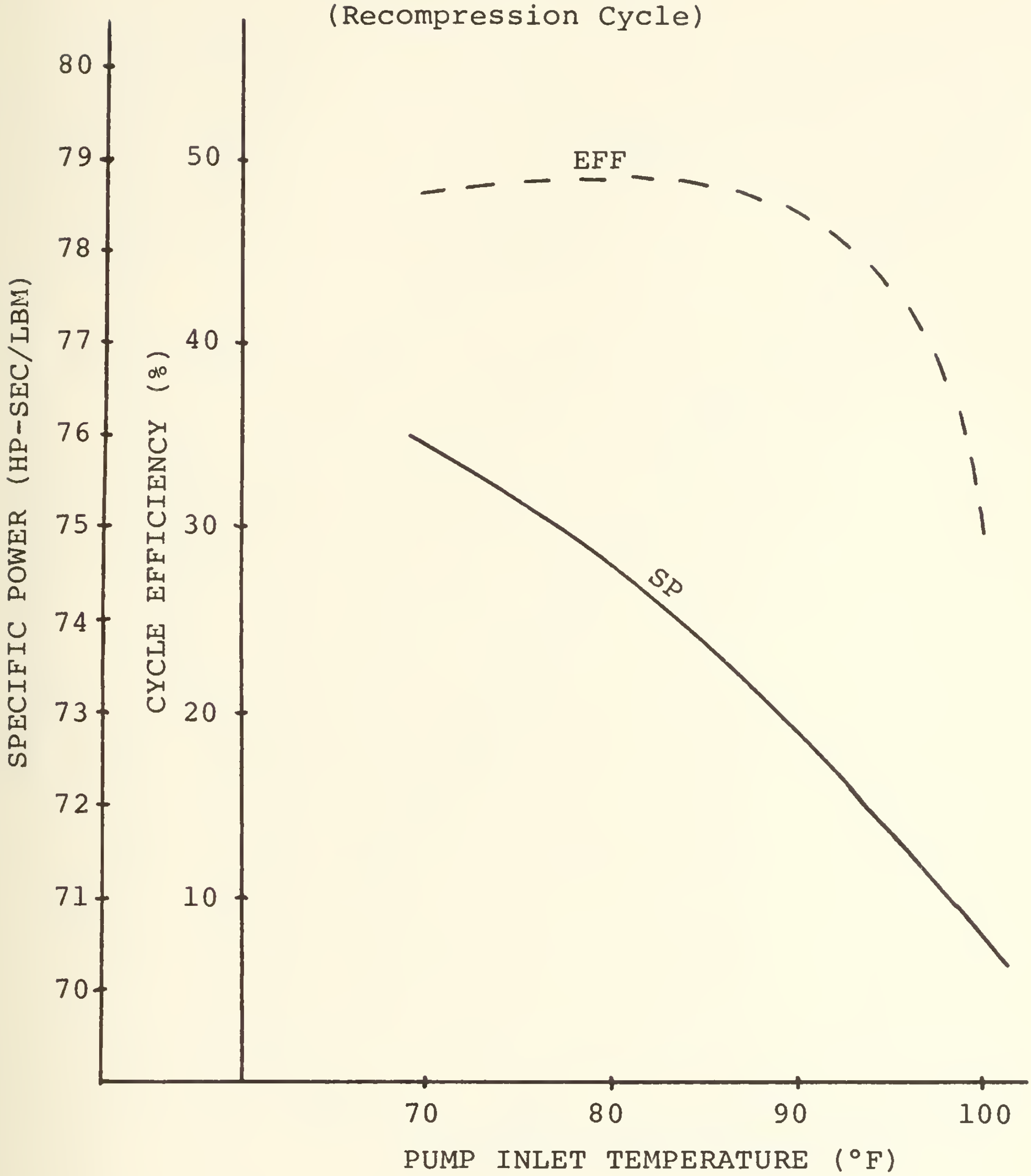


FIGURE 9

Turbine Inlet Temperature vs. Cycle Efficiency
and Specific Power

(Recompression Cycle)

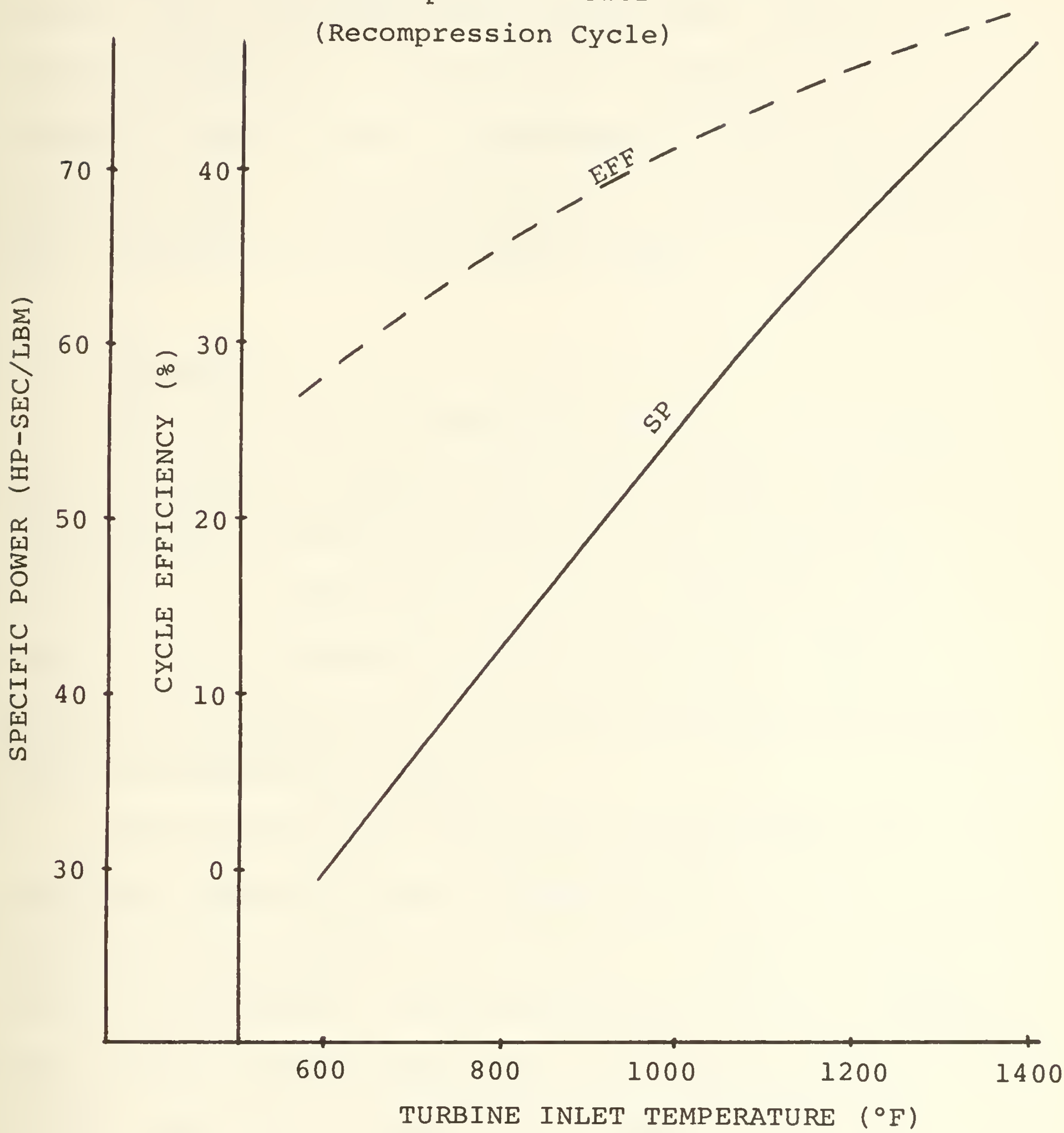


FIGURE 10

versus cycle efficiency and specific power output is given in Figure 11. As explained in section 2.2.3, changes in power level is achieved by varying the pressure ratio. Figure 12 shows the results of specific fuel consumption over wide power ranges.

2.4 Conclusion

The design and off-design performance of the Basic and Recompression Engines have been analyzed. The thermodynamic approach was shown to be valid by the agreement with Reference (9) for the efficiency and specific fuel consumptions calculated for the Basic Engine; with Reference (6) for the efficiency calculated for the Recompression Engine.

The Recompression Engine has the potential for achieving a specific fuel consumption of .32 Lbm fuel/SHP-HR as compared to a SFC of .37 Lbm fuel/SHP-HR for the Basic Engine. Both engines have lower consumption than current aircraft derivative gas turbines (SFC $\approx$ .4). On the other hand, better fuel consumption is at the expense of engine complexity. That is, the Basic Engine is more complex than the gas turbine and the Recompression Engine is more complex than the Basic Engine.

Thus, the promising gains from the Recompression

Turbine Pressure Ratio vs. Cycle Efficiency
and Specific Power

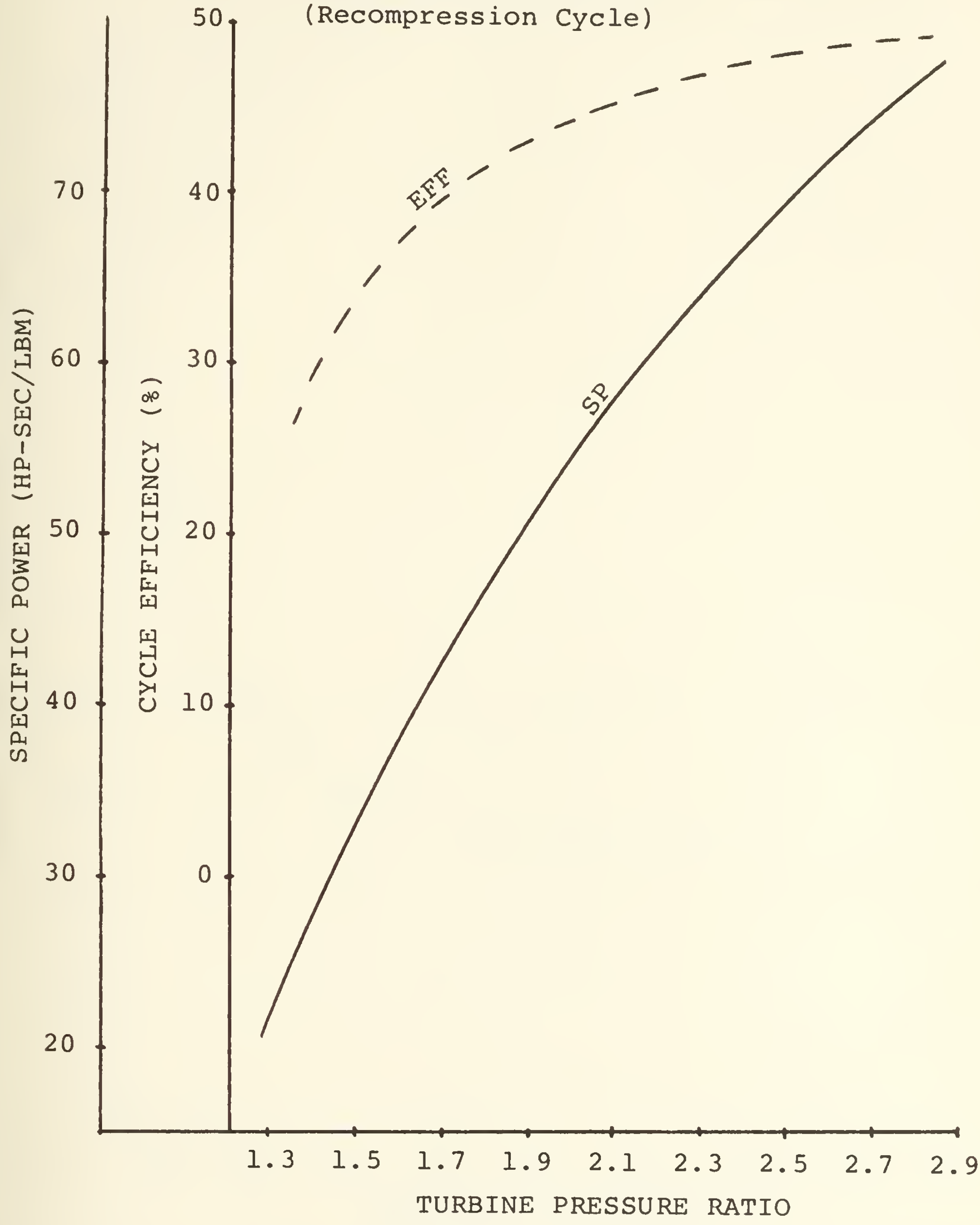


FIGURE 11

Percentage of Power vs. Specific Fuel Consumption
(Recompression Cycle)

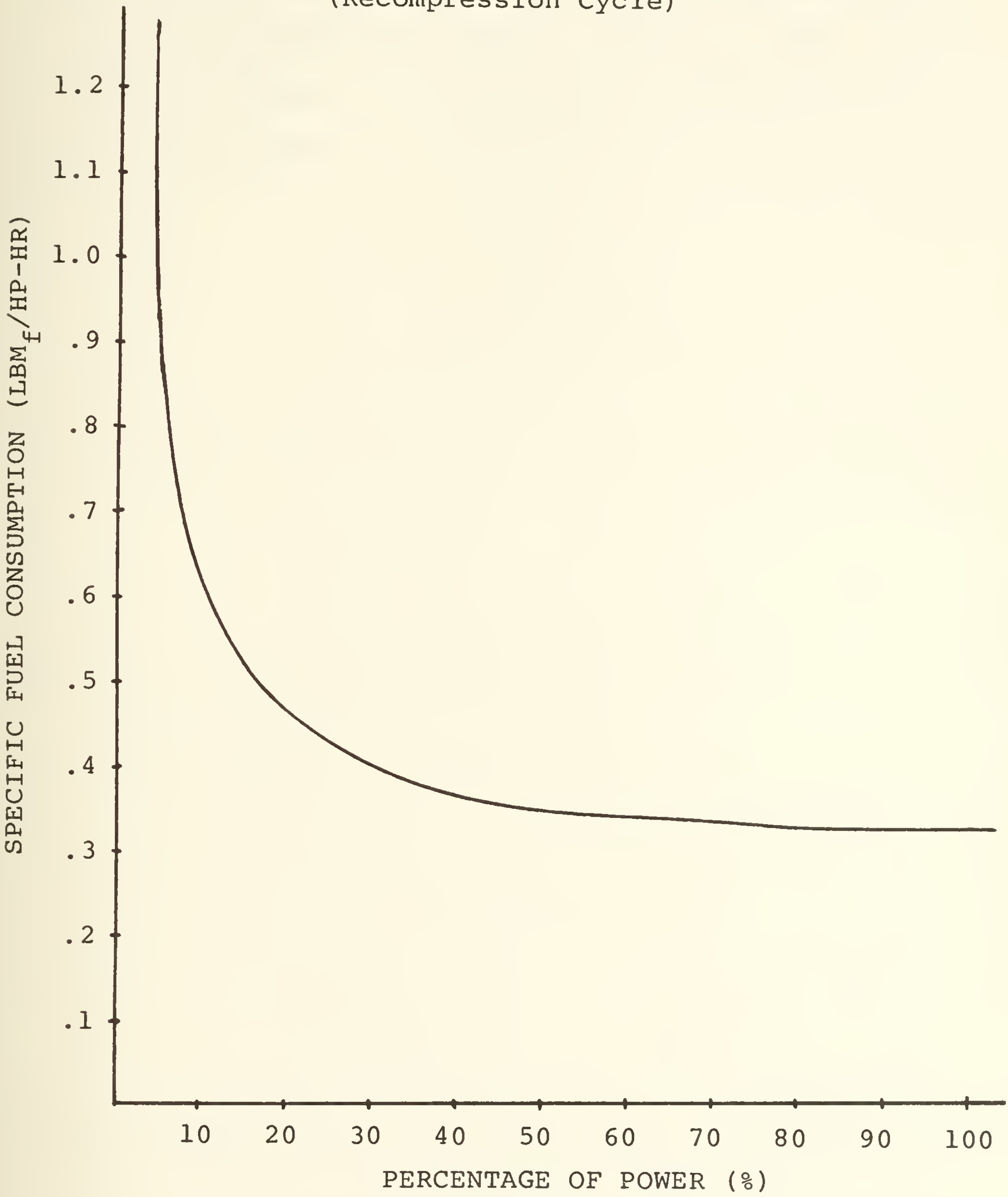


FIGURE 12

Engine or the Basic Engine should not be misinterpreted by the ship designer as enormous savings in fuel, weight, or space. Chapter 3 follows with a discussion on the size of the plants.

CHAPTER 3

COMPONENT SIZING

3.0 Introduction

In Chapter 2 it was shown that the Basic and Recompression cycles are feasible thermodynamically. This chapter concentrates on the design of major components necessary to determine the overall size of the two engines. First, preliminary design of turbomachinery and heat exchangers are performed. Secondly, from a "model" design, complete engines are conceptualized for the basic and recompression cycles based on practical considerations.

3.1 Turbomachinery - Basic Engine

3.1.1 Power Drive Turbine

This unit is designed to deliver the required 20,000 SHP. Using preliminary design rules given by Carmichael (5), the power turbine is assumed to be a two-stage axial flow unit. It is intended to operate at 21,600 RPM and requires a gear box to achieve 3600 RPM at the main shaft. This configuration is a small unit with a tip radius of approximately 4 inches. Therefore, its size is considered to have little impact on the overall design.

3.1.2 Pump

The pump compresses the working fluid from the cycle's low pressure to the high pressure of the system. Design rules of Reference (4) indicate that the unit can be centrifugal, operating at 28,800 RPM. Reduction through the gear box of 8:1 is required. The unit is approximately 3 inches at diffuser exit and small in total size.

3.1.3 Pump Drive Turbine

The pump drive turbine provides power to the pump. Again from Reference (5), the pump drive turbine is assumed to be a single-stage axial flow turbine. A 3:1 reduction is required by the gear box to obtain 3600 RPM. The tip radius is found to be approximately 5 inches and overall dimensions are small, like the power drive turbine, and its weight is considered negligible as compared to the weight of the heat exchangers.

3.2 Heat Exchangers - Basic Engine

3.2.1 Recuperator

The recuperator is a heat exchanger that exchanges heat between the cold side of the cycle and the hot fluid leaving the turbine; as such, reducing the required heat

input. A shell-and-tube heat exchanger configuration is utilized with a cross-counter flow arrangement. Parallel units are considered in a U-tube arrangement. The unit is designed to be able to operate safely at 1-1/2 times the shell pressure.

The size of the unit is determined by utilizing the computer program described in Appendix II. The basic program is being developed by Mahoney (19). Since many changes are made to the program by this writer, the author has consented to its reproduction here. Computer runs were made on the IBM 370, Model 168.

The length and weight of the recuperator is strongly affected by the tube diameter selected. As such, the designer must concern himself with an acceptable tube size based on anticipated technology. On the other hand, he must work within any given or predicted constraints. Figure 13 shows how length and weight increase as tube diameter increases. Section 3.5 provides the discussion of the final selection of the size of the recuperator.

Extensive work on heat exchanger materials is not performed. A yield stress of 20,000 pounds force per square inch is used for calculation purposes. Also, the density for stainless steel is selected for weight calculations.

Tube Diameter vs. Length and Weight of Recuperator
(Basic Engine)

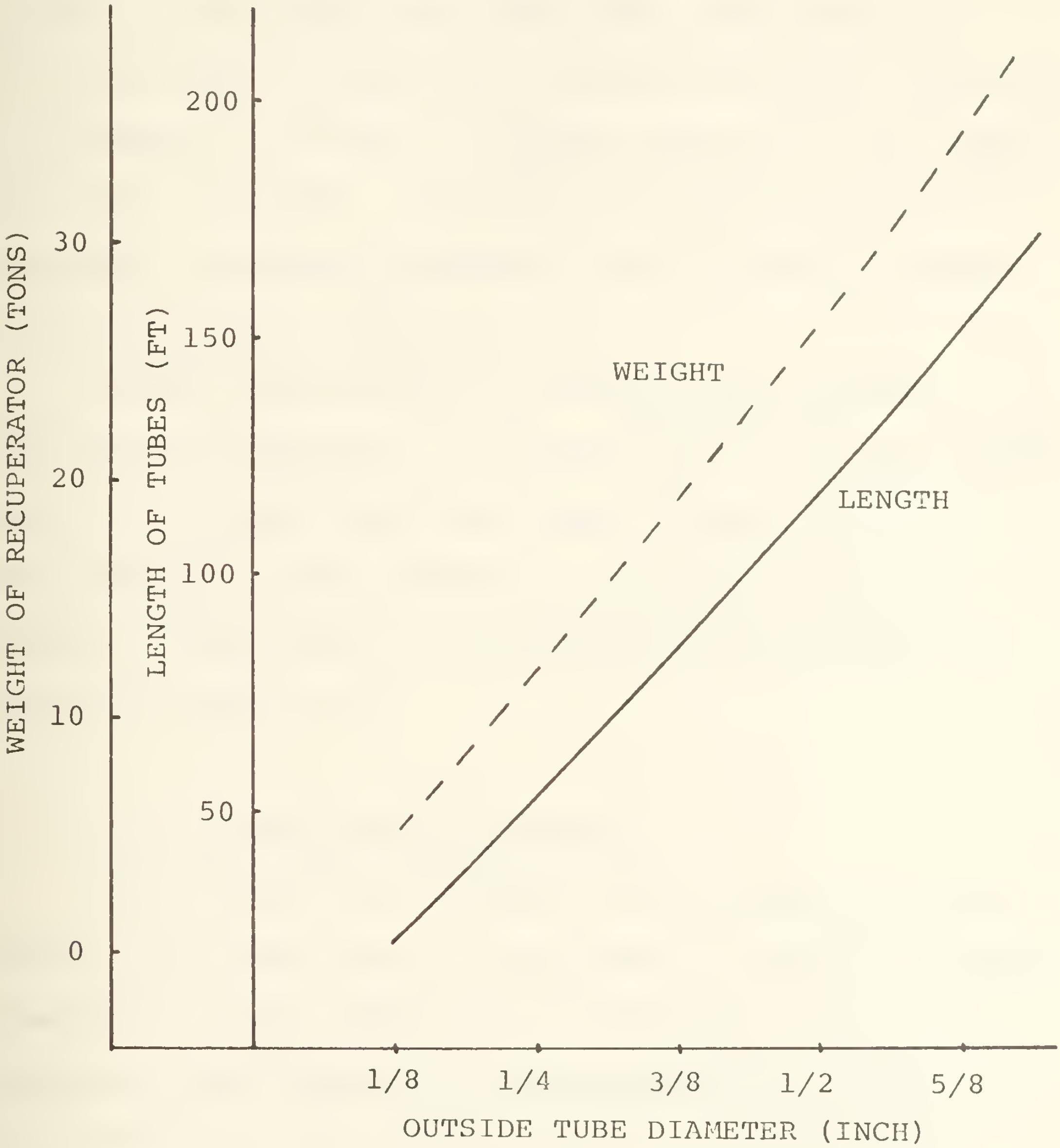


FIGURE 13

3.2.2 Secondary Heat Exchanger

The secondary heat exchanger cools the working fluid to the 80°F temperature required at pump inlet. A parallel set of shell-and-tube heat exchangers are utilized with a cross-counter flow arrangement. The unit is designed to be able to operate safely at 1-1/2 times the shell pressure. The cooler is designed based on a velocity of sea water between 8 and 10 feet per second as recommended by Reference (20).

Sizing calculations are based on the computer program in Appendix II. A yield stress of 20,000 and the density of Cooper Nickel are used. Figure 14 depicts the effects of tube diameter on exchanger length and weight. Discussion of the selected heat exchanger is given in section 3.5.

3.2.3 Primary Heat Exchanger

The primary heat exchanger is an external heating source which adds heat to the system at constant pressure. Analysis of this component is considered in two parts - combustor and preheater. The combustor is considered to be a difficult unit and represents considerable risk in the development of the engine. It is modeled as a shell-and-tube unit with parallel flow. Although radiation

Tube Diameter vs. Length and Weight of Cooler
(Basic Engine)

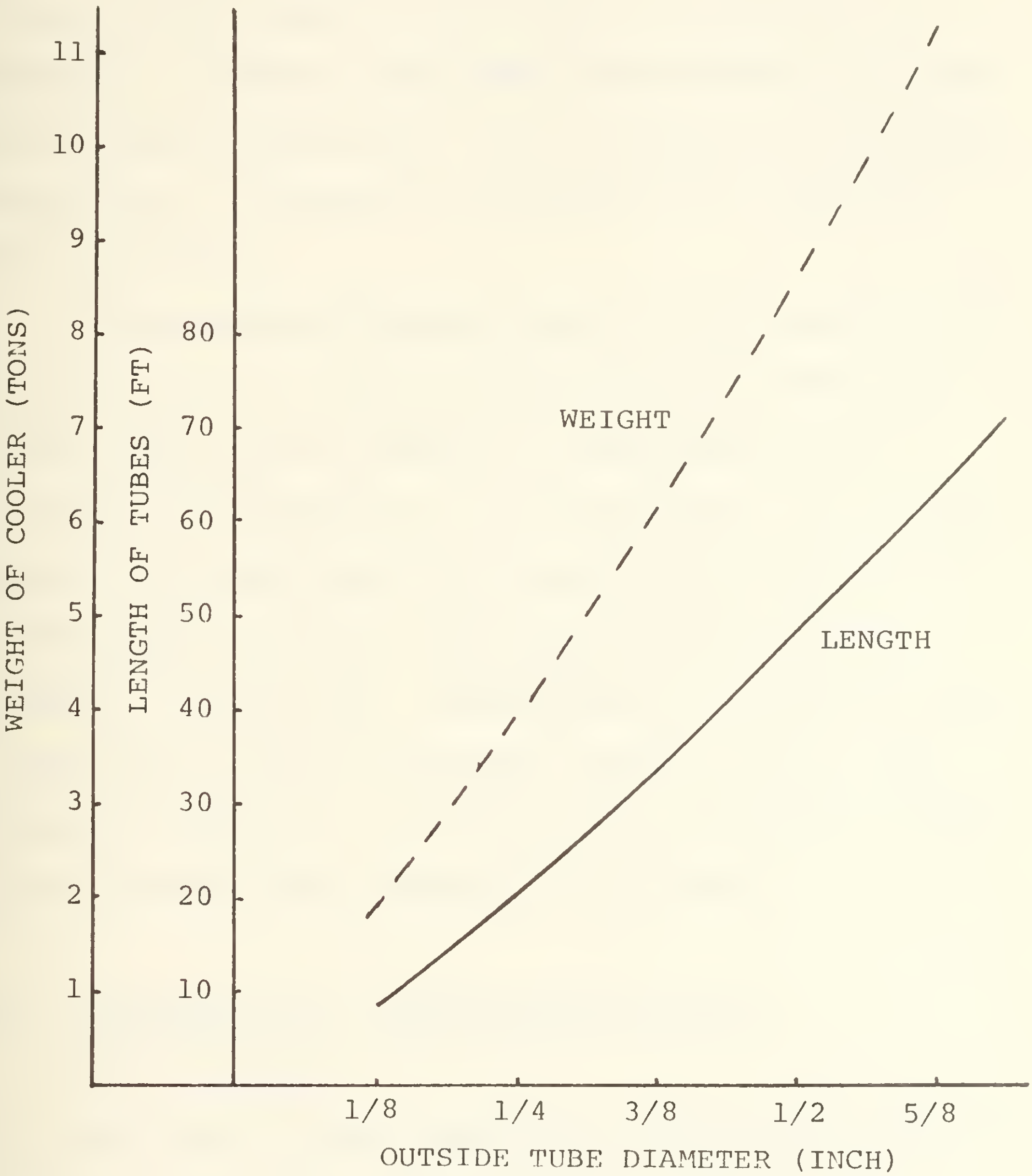


FIGURE 14

from the flame is important, its effects are not considered. The temperature of the working fluid entering the furnace is high; thus, a preheater is required. A counter flow shell-and-tube heat exchanger is considered appropriate. The combustor and preheater combination is designed to withstand 1-1/2 times its shell pressure.

Sizing calculations are based on the program found in Appendix II. A yield stress of 35,000 pounds per square inch and the density of stainless steel are considered satisfactory. An investigation of pressure drops on the exchanger are considered and found to have little effect on size. To illustrate this point, Figure 15 is provided. Consideration of Figures 16 and 17 show that length and weight increase as the tube diameter increases. In section 3.5 a reasonable design of the primary heat exchanger is discussed.

3.3 Turbomachinery - Recompression Engine

3.3.1 General

The power turbine, pump drive turbine, and pump are designed to the same requirements as presented in section 3.1. As RPM and gear box ratio changes are found to be slight from those present for the basic engine,

Volume of Combustor vs. Core Pressure Drops

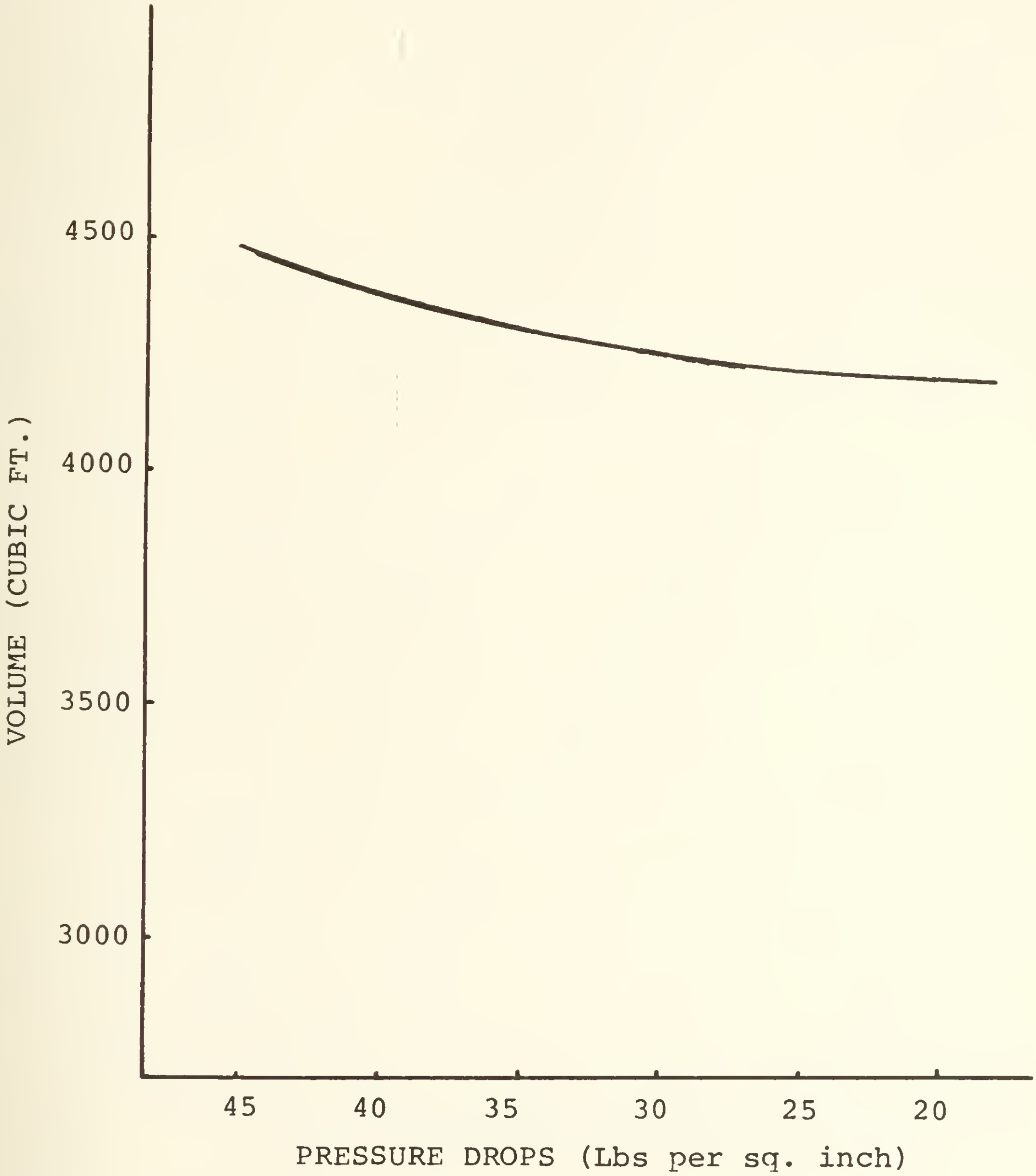


FIGURE 15

Tube Diameter vs. Length and Weight of Combustor
(Basic)

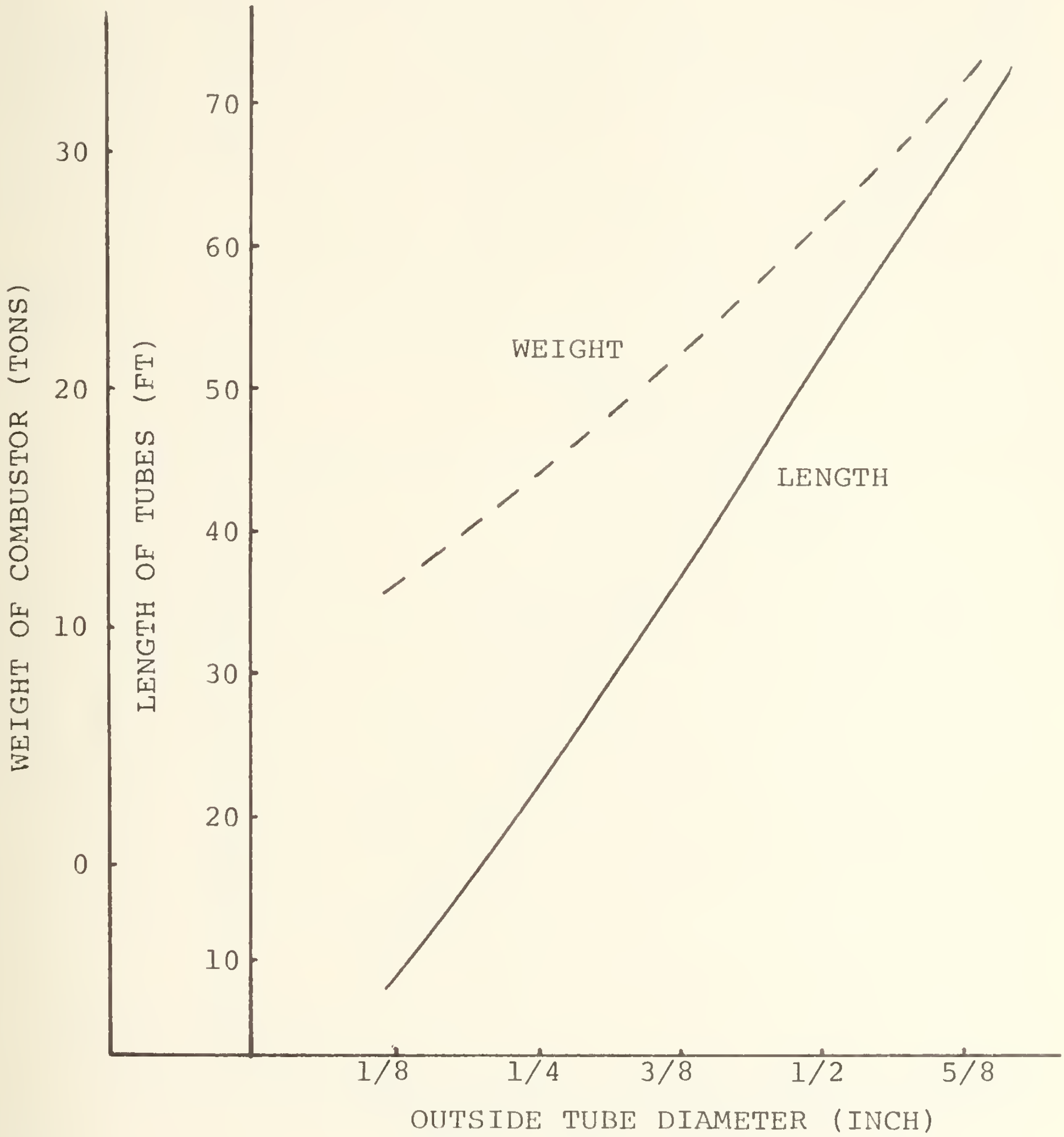


FIGURE 16

Tube Diameter vs. Length and Weight of Preheater
(Basic)

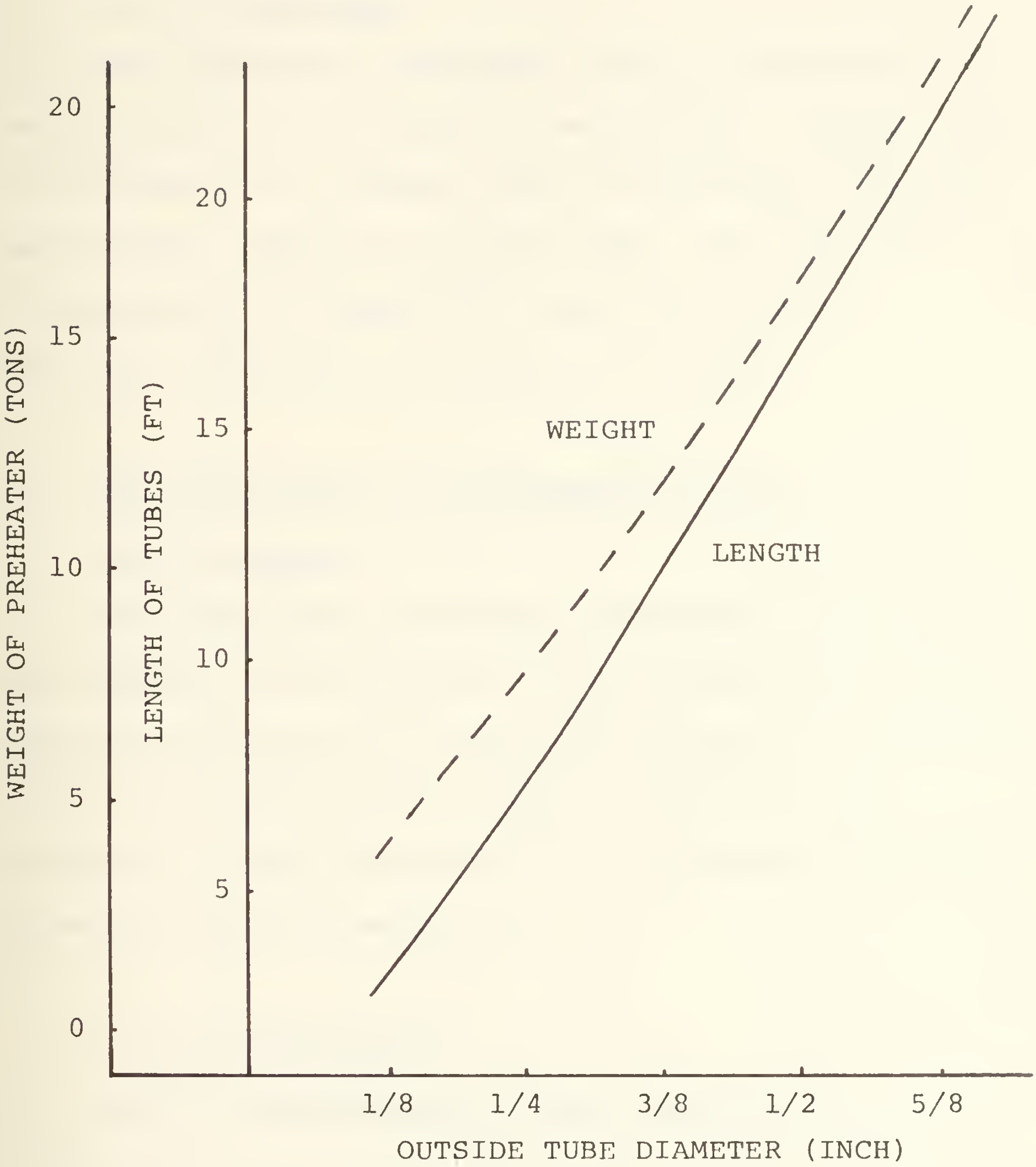


FIGURE 17

their numbers are not presented here.

3.3.2 Compressor

The compressor compresses a small percentage of the working fluid as it exits the recuperator. Design rules of Reference (4) indicate that the compressor could be centrifugal operating at 50,400 RPM. The radius at diffuser exit is found to be less than 2 inches. Therefore, the unit is assumed to be small.

3.4 Heat Exchangers - Recompression Engine

3.4.1 General

The same design procedures discussed in section 3.2 are employed for the design of the recompression engine. Figures 18 through 20 illustrate variations in component length and weight for the cooler, combustor, and preheater. Final selection of the individual component sizes are given in section 3.5.

3.4.2 Recuperators

The low temperature and high temperature recuperators are designed using the computer program in Appendix II. It is assumed that a suitable arrangement of the two recuperators can be easily achieved with both

Tube Diameter vs. Length and Weight of Cooler
(Recompression)

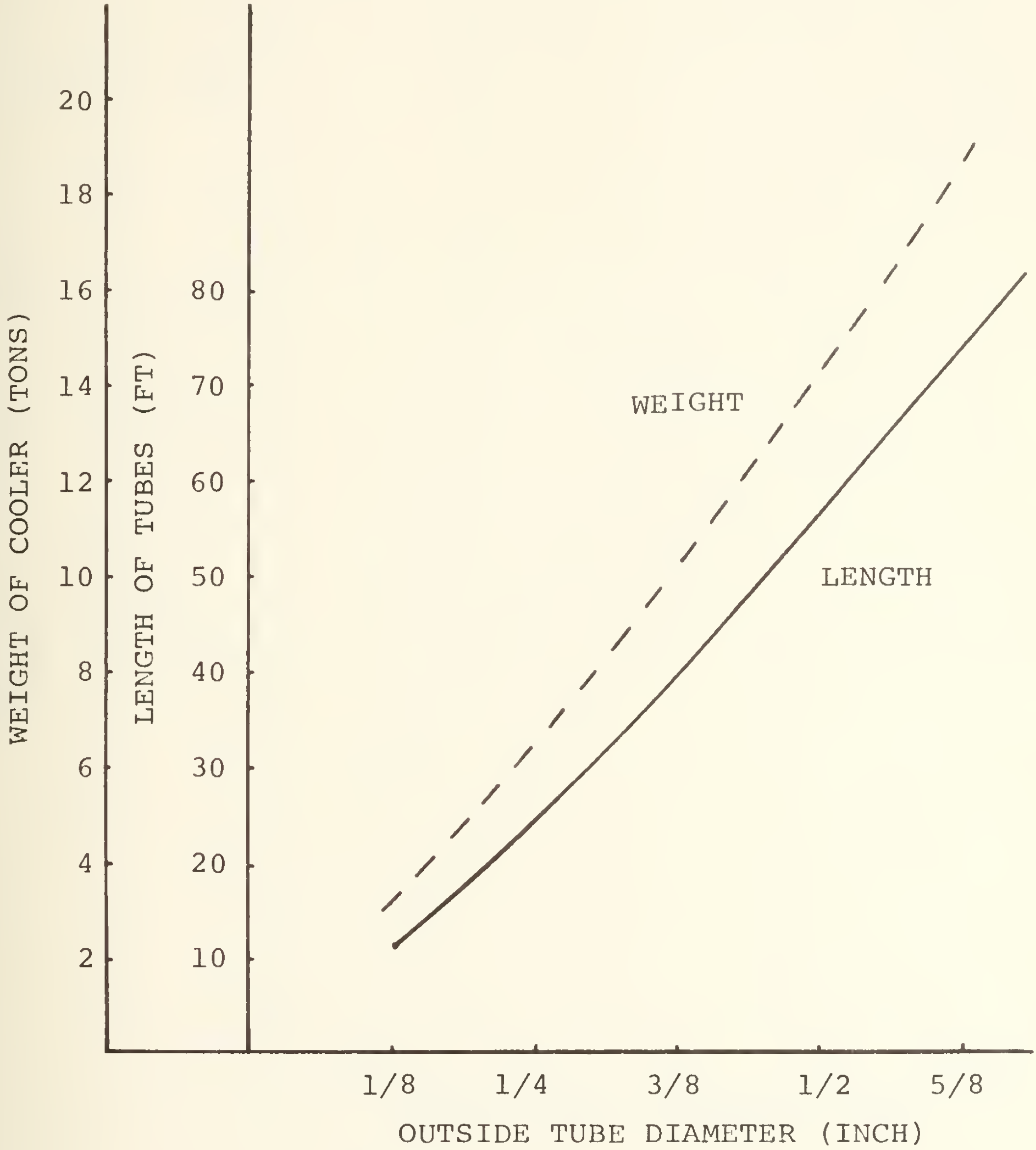


FIGURE 18

Tube Diameter vs. Length and Weight of Combustor
(Recompression)

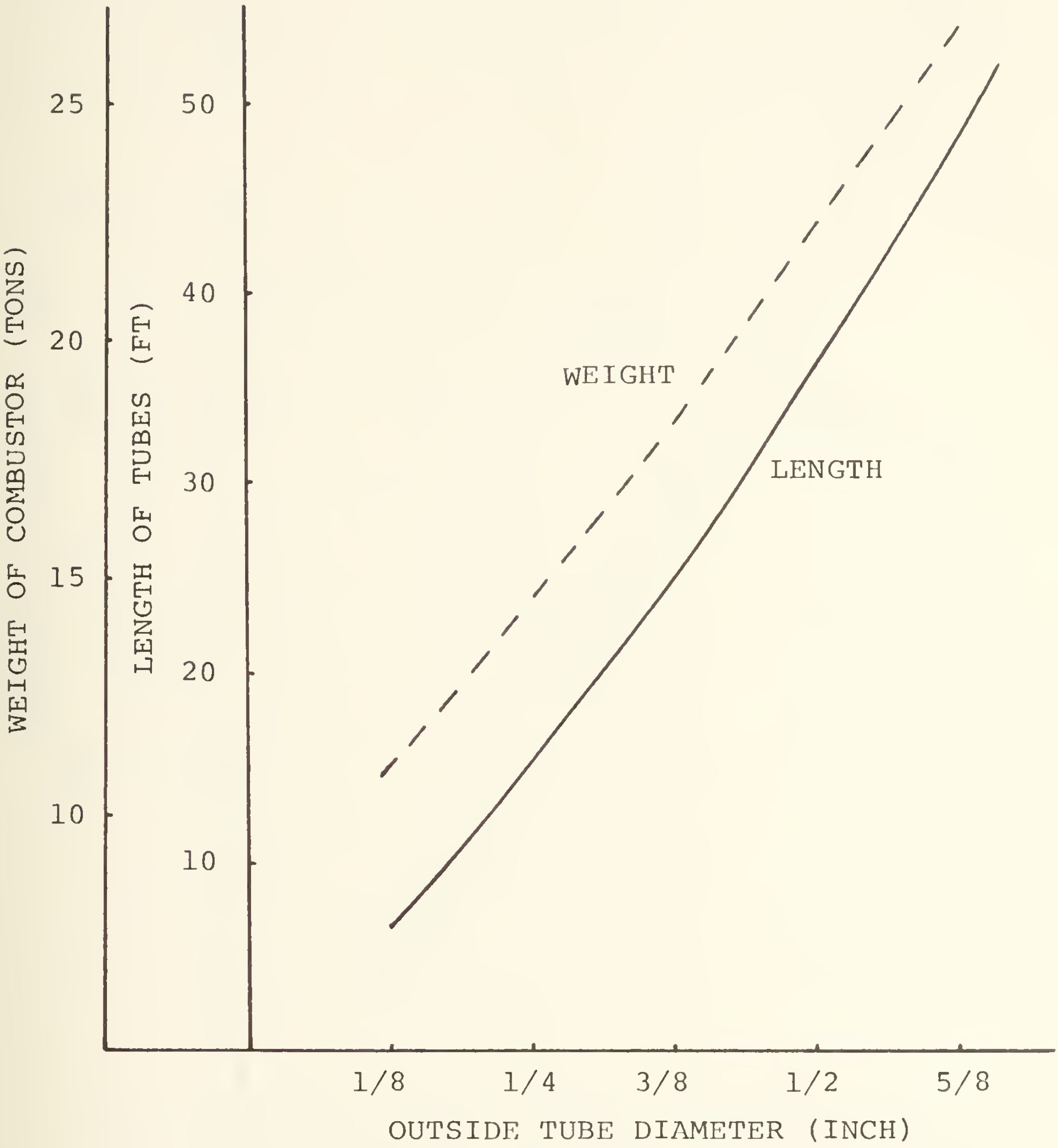


FIGURE 19

Tube Diameter vs. Length and Weight of Preheater
(Recompression)

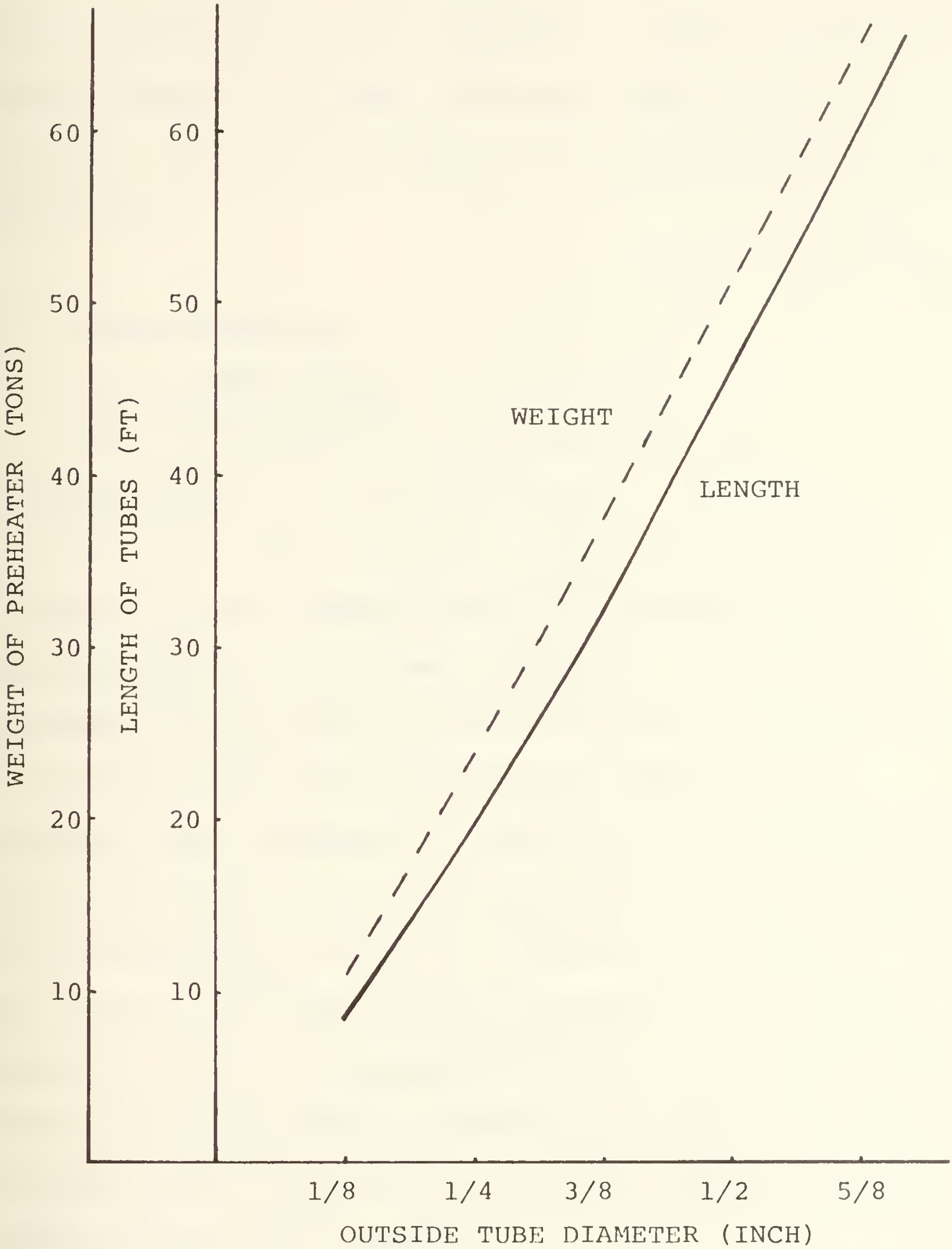


FIGURE 20

units on the sides of the combustor. Figures 21 and 22 depict recuperator length and weight versus tube diameter. Section 3.5 follows with a discussion on final selection.

3.5 Design Selection

3.5.1 Model Design

Feher (9) provides an excellent graphical representation of a conceptual engine. Figure 23 is reproduced for easy reference. Investigation of this conceptual layout reveals that the turbomachinery is small compared to the other components. Further consideration of Figure 23 shows that the recuperator is a shell-and-tube with a parallel arrangement. The secondary heat exchanger or cooler is also considered to be shell-and-tube with the working fluid flowing counter to the entering sea water. Not shown on the figure is the internal arrangement of the primary heating source. However, a pictorial representation of a combustion heat source is illustrated in Reference (9). The unit shown indicates that a preheater is used in conjunction with a carbon dioxide (CO_2) heater.

As this conceptual layout of a 20,000 HP Feher Cycle Marine Engine illustrates the major components required

Tube Diameter vs. Length and Weight of
Low Temperature Recuperator
(Recompression)

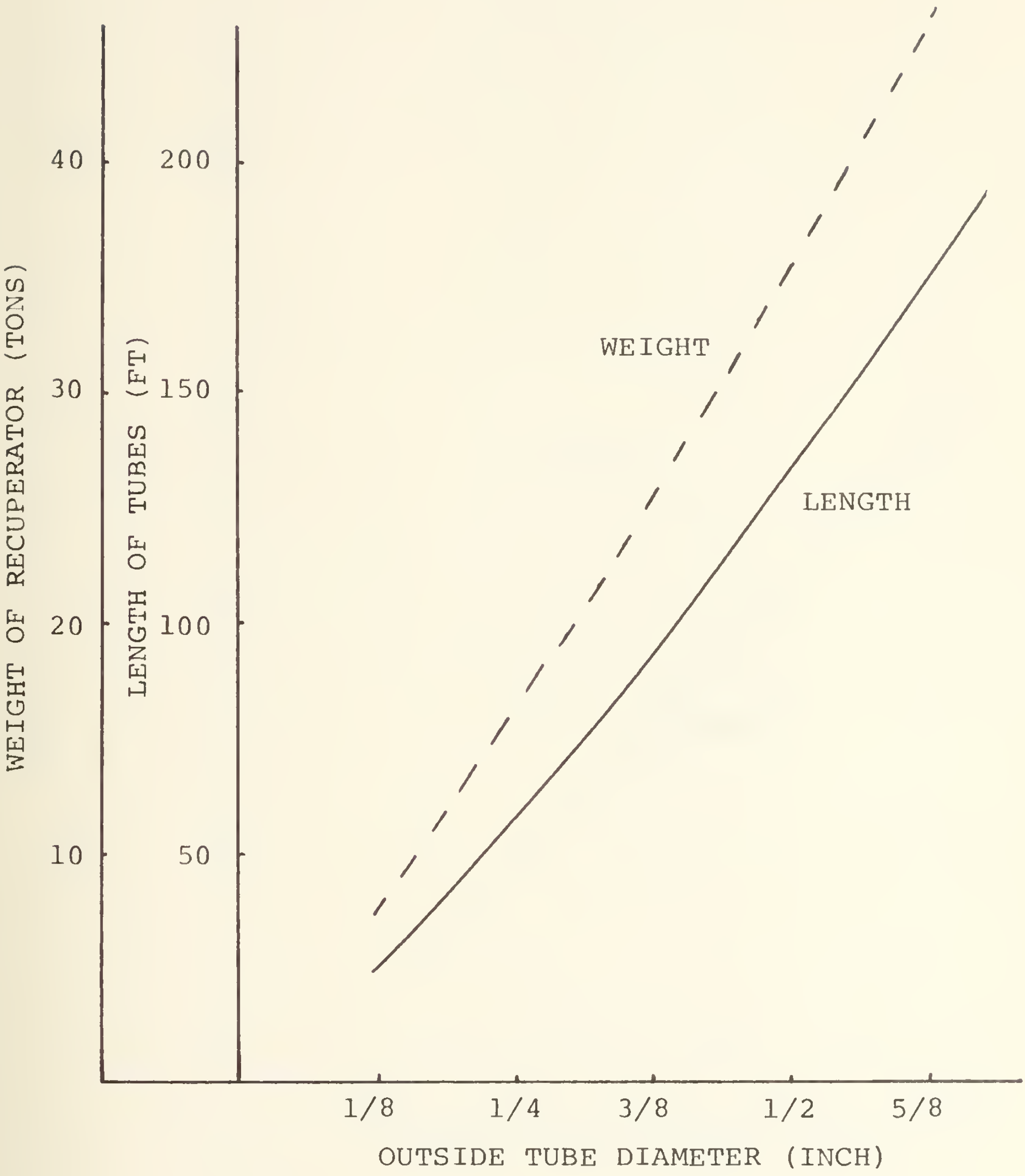


FIGURE 21

Tube Diameter vs. Length and Weight of
High Temperature Recuperator
(Recompression)

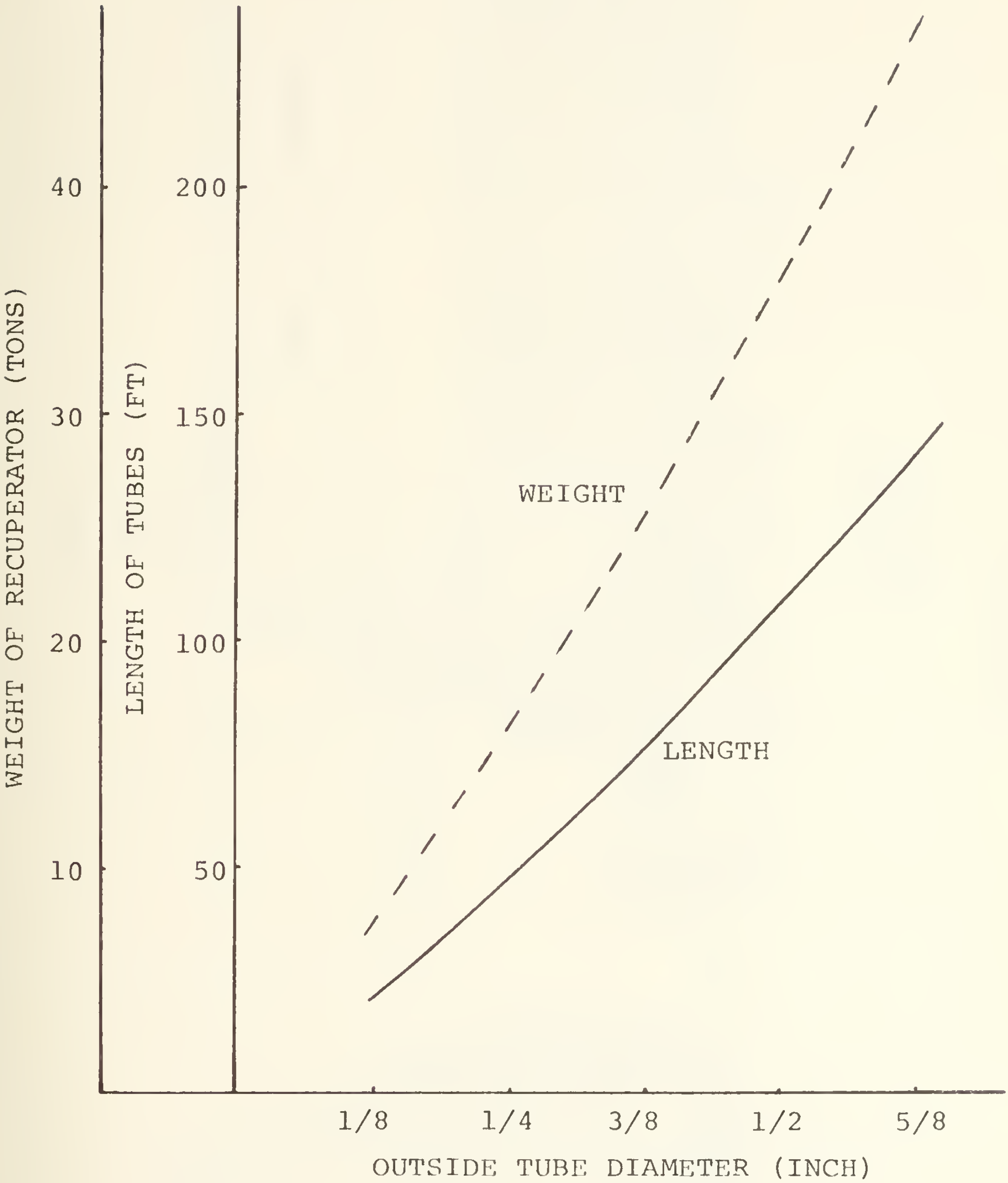


FIGURE 22

CONCEPTUAL LAYOUT OF 20,000 HP FEHER MARINE ENGINE

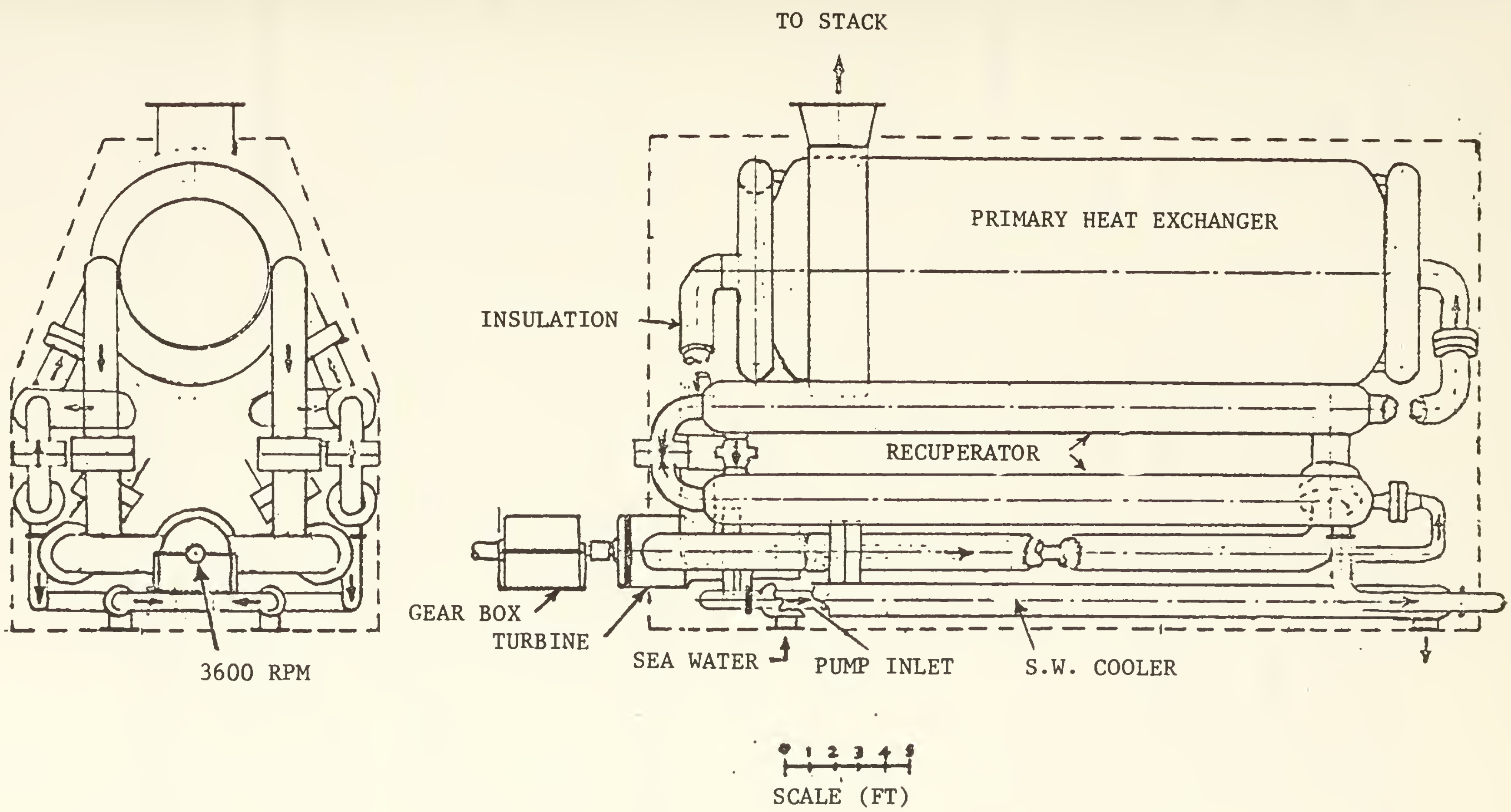


FIGURE 23

for a shipboard application, it is taken as the model design. Reference (9) gives the engine weight (WET) to be 157,074 lbs. (70.12 tons) and a total volume of 8,360 cubic feet. If it is assumed that similar preliminary design procedures are used, individual component sizes can be determined within certain tolerances. From Figures 13, 14, 16, 17, and 23, the following design information is assumed: recuperator ≃ 1/4 inch, cooler ≃ 3/8 inch, preheater ≃ 3/8 inch, combustor ≃ 1/4 inch. The turbomachinery is considered insignificant in size as compared to the heat exchangers. These diameters are considered to be within ±1/16 inch of their actual design value.

It is conceivable that technology would be available after the development of a 20,000 HP Feher Engine to remedy the problems associated with the high combustion products in the primary heat exchanger and fouling in the secondary heat exchanger. However, with small tubes considerable risk would be involved and "good engineering judgment" would be questioned. Therefore, a reasonable outside diameter for the primary heat exchanger should be a minimum of 1/2 inch. This size would allow for easier maintenance at reduced risk but at the expense of an increase in size.

3.5.2. Recommended Engines

Tables 1 and 2 summarize the design of the "model" basic engine and the recommended basic engine. To account for the discrepancies in component design, the individual heat exchanger weights provided in Appendix II are subtracted from the total weight of the model. The turbomachinery and piping requirements are considered adequate and are held constant. Therefore, to determine the new engine weight, the recommended new heat exchanger weights are added to the weight of the turbomachinery and piping. Table 3 summarizes the design of a recompression engine based on diameters of 1/4 inch, 3/8 inch, 3/8 inch, and 1/4 inch for the recuperators, cooler, preheater, and combustor respectively. These diameters are those assumed to be used by the "model" engine. The weight is determined by adding heat exchanger weights to the weight of the turbomachinery as explained in the preceeding paragraph. The additional weight of the compressor is considered to be less than one ton and therefore insignificant. Table 4 is provided to describe the recompression engine using 1/2 inch tubes for the primary heat exchanger.

BASIC ENGINE SUMMARY

COMPONENT	RECUPERATOR	S.W. COOLER	COMBUSTOR		TURBOMACHINERY (CONSTANTS)
			P.H.	C.	
DIAMETER (IN)	1/4	3/8	3/8	1/4	
LENGTH (FT)	54	34	12	22	
VOLUME (FT^3)	110.3	60.3	537.5	1270	
WEIGHT (TONS)	11.72	6.2	11.66	16.2	25.34
TOTAL WEIGHT (WET) = 70.12 tons					

TABLE 1

RECOMMENDED BASIC ENGINE SUMMARY

COMPONENT	RECUPERATOR	S.W. COOLER	COMBUSTOR	TURBOMACHINERY (+ CONSTANTS) x 1.2
DIAMETER (IN)	1/2	5/8	1/2	---
LENGTH (FT)	158	65	75	---
VOLUME (FT^3)	330	111.3	3800	---
WEIGHT (TONS)	34	11.1	42.5	25.34
TOTAL WEIGHT (WET) = 113 tons				

TABLE 2

RECOMPRESSION ENGINE SUMMARY

COMPONENT	RECUPERATOR		S.W. COOLER	COMBUSTOR		TURBOMACHINERY (+ CONSTANTS)
	LOW	HIGH		P.H.	C.	
DIAMETER (IN)	1/4	1/4	3/8	3/8	1/4	
LENGTH (FT)	60	50	42	32	20	
VOLUME (FT^3)	162.0	176	111	1600	920	
WEIGHT (TONS)	15.7	16.5	10.3	36.4	14.3	30.4
TOTAL WEIGHT (WET) = 120 tons						

TABLE 3

RECOMMENDED RECOMPRESSION ENGINE SUMMARY

COMPONENT	RECUPERATOR		S.W. COOLER	COMBUSTOR	TURBOMACHINERY (+ CONSTANTS)
	LOW	HIGH			
DIAMETER (IN)	1/2	5/8	5/8	1/2	
LENGTH (FT)	136	142	76	85	
VOLUME (FT^3)	380	550	205	4500	
WEIGHT (TONS)	34.9	47.3	18.5	72.5	30.4
TOTAL WEIGHT (WET) = 200 tons					

TABLE 4

3.6 Conclusions

In conclusion, sizes for the major components of the model, basic, model-recompression, and recompression engines have been analyzed. Individual components were sized using design rules presented in References (4) and (5) and the computer program described in Appendix II.

It is believed that the methods used in this chapter are considered adequate for the scope of this work. Moreover, to account for any differences in design methods, the data provided on the model engine was used as the base design. That is, any discrepancies encountered were treated as a constant in the design and added to the weight or length as appropriate in the proposed designs.

Turbomachinery was found to be small and to have little impact on the overall size. Primary heat exchanger tubing is recommended to be a minimum of 1/2 inch for maintenance and reliability purposes. The total engine size for the four designs have been determined and will be utilized in Chapter 4.

CHAPTER 4

SHIP UTILIZATION

4.0 Introduction

The results of the thermodynamic analysis in Chapter 2 have shown that gains in specific fuel consumption and efficiency are possible with the Feher Supercritical Cycle. The objective of this chapter is to perform a complete ship-systems analysis to determine if the advantage in specific fuel consumption and efficiency for the four CO_2 engines discussed in Chapter 3 can be utilized on a naval combatant. This goal will be achieved by determining if there is an increase in ship performance as compared to an existing gas turbine powered ship.

When evaluating these alternative designs, the conclusions will be based on the "true cost" of the subsystem (propulsion plant). Cost is defined as weight, volume, fuel, and other design indices affecting ship size. True cost implies not only consideration of the direct but also indirect costs involved in incorporating the subsystem into the ship. The direct costs include the contribution from the subsystem. The indirect costs include ship growth as a result of the added machinery in terms of weight, volume, electrical power, fuel, and

manning in the rest of the ship.

To assess the total ship's performance, two approaches are considered. First, for a specific set of architectural requirements, each ship is evaluated to determine its true performance. Secondly, by fixing performance levels, a feasible ship is obtained with a new set of architectural requirements.

Holmes (14) outlines performance elements by dividing them into two areas: systems-engineering performance and operational performance. The operational elements are the direct areas of basic performance, such as speed, range, and electrical power. Flexibility, standardization, risk, reliability, maintainability, availability, survivability, and signature are examples of the system-engineering performance elements. Only operational performance is considered in this work.

4.1 Ship Synthesis Model

4.1.1 Discussion

The method used in comparing the four CO_2 engines is obtained by utilizing a ship synthesis model developed by Reed (23). The computerized model presents a method for estimating the weight, volume, center of gravity, electrical load, and other overall ship

characteristics of conceptual as well as existing naval surface displacement ships. The model is found to have applications in conducting feasibility studies, system analyses, updating design predictions, and conducting comparative studies. Therefore, these features are attractive for the purposes here.

The most important characteristic of the computer model is that it allows consistency among the studies. The consistency built into the model standard calculations allows the study results to be compared without the possibility of bias favoring certain concepts. Thus, specific questions can be asked concerning each design with excellent assurance that comparable answers are obtained.

4.1.2 Changes to Model

The technique used to develop most of the relationships listed in Reference (23) was linear regression for two variables by the method of least squares. The author of the synthesis model also states that a few equations were developed to best fit existing curves, e.g., linear approximations to the powering worm curve used in horsepower calculations.

The classification systems used to identify

functional and weight groups were the U.S. Navy Ship Space Classification System Number and the NAVSHIPS B.S.C.I. Weight Group (1965). Table 5 illustrates the two broad areas that change when different propulsion plants are selected. Table 6 identifies those sub group items which change by descriptive title. Alterations can be made to the computer program by replacing the basic equations used or directly inputting the desired item. Both methods are used for the models analyzed.

As the synthesis model does not perform calculations for a supercritical engine, substitutions are required. However, to minimize the number of changes and maintain consistency in comparing the gas turbine engine with the supercritical engines, the routine for the gas turbine engine is used. When the items identified in the preceeding paragraph are considered to be different from the routine for the gas turbine, the following changes are introduced. W(112), propulsion plant foundation weight, is assumed to be approximately that for steam power plants. Thus, the following equation is utilized.

$$W(112) = .6\ SHP^{.3348} \qquad [4.1]$$

The weights of sub groups 200 and 201 are known from

PERTINENT CLASSIFICATION SYSTEMS

FUNCTIONAL NAME	U.S. NAVY SHIP SPACE CLASSIFICATION SYSTEM NUMBER	NAVSHIPS B.S.C.I. WEIGHT GROUP
Machinery Box	3.21, 3.22, 3.23, 3.24, 3.25, 3.27, 3.12, 3.31, 3.33	200, 201, 202, 204, 206, 207, 208, 209, 210, 211, 251, 502, 503, 504, 512, 513, 514, 517, 527, 551, 603
Uptakes	3.26	205

TABLE 5

B.S.C.I. WEIGHT GROUPS CHANGES

Sub Group	Description
112	Propulsion Foundations
200	Boilers and Energy Converters
201	Propulsion Units
202	Main Condensers & Air Ejectors
204	Combustion Air Supply
205	Uptakes and Smoke Pipes

TABLE 6

Chapter 2. Therefore, the override feature of the program is employed by inputting the weight, vertical center of gravity, and volume. The values for main condensers and air ejectors are set to zero. Calculations of the combustion air supply, uptakes, and smoke pipes reveal that the air required for the external heat source resembles that required for boilers operating with approximately 15% excess air. For this reason, Equations [4.2] and [4.3] are considered appropriate.

$$W(204) = 1.05 \times 10^{-4}\ SHP + 6.5 \qquad [4.2]$$

$$W(205) = .000181\ SHP + 3.18 \qquad [4.3]$$

To calculate the required fuel at endurance, the program utilizes Equation [4.4].

$$SFCAED = SFCFP \times 1.2298\left(1 - \frac{EDPWPE}{SHP/NE}\right) \qquad [4.4]$$

where SFCFP is defined by Equation [4.5] as

$$SFCFP = .0000101 \times \frac{SHP}{NE} + 0.627 \qquad [4.5]$$

Equation [4.4] shows that average endurance specific

fuel consumption is calculated as a function of the engine's full power specific fuel consumption. But a more precise method to determine the average endurance specific fuel is by directly calculating the consumption at endurance power. Equations [4.6] through [4.8] are derived by using a least squares method to fit a typical second generation marine gas turbine specific fuel consumption curve. The curve is split into three regions for better accuracy.

$$\left\{\frac{AVEDPW}{NE} \le 2500.99\right\} \; SFCAED = .5245314 + .9655517 \times 10^{-3}\left(\frac{AVEDPW}{NE}\right) - .6280953 \times 10^{-6}\left(\frac{AVEDPW}{NE}\right)^2 + .1145368 \times 10^{-9}\left(\frac{AVEDPW}{NE}\right)^3 \qquad [4.6]$$

$$\left\{2501 \le \frac{AVEDPW}{NE} \le 10000\right\} \; SFCAED = 1.148954 - .1772191 \times 10^{-3}\left(\frac{AVEDPW}{NE}\right) + .167462 \times 10^{-7}\left(\frac{AVEDPW}{NE}\right)^2$$

$$- .585312 \times 10^{-12} \left(\frac{AVEDPW}{NE}\right)^3 \qquad [4.7]$$

$$\left\{\frac{AVEDPW}{NE} \geq 10000.01\right\} \ SFCAED = .7560333$$

$$- .5187021 \times 10^{-4} \left(\frac{AVEDPW}{NE}\right)$$

$$+ .2857238 \times 10^{-8} \left(\frac{AVEDPW}{NE}\right)^2$$

$$- .5779741 \times 10^{-13} \left(\frac{AVEDPW}{NE}\right)^3 \qquad [4.8]$$

The same procedure is performed for the basic and recompression engines' curves. Their equations are not presented here. Other differences in the types of engines are considered insignificant.

4.2 Ships Description

4.2.1 Baseline Ship

The FFG7's represent a new class of naval patrol frigates. The design philosophy requires the ships to maximize performance while holding cost constant. One means of meeting this goal was through the selection of the gas turbine engine as the propulsion plant because

of its low weight per shaft horsepower, rapid response to power changes, lower manning levels, maintenance requirements, and modularity. Another method of holding down the cost was by minimizing the total ship size. Therefore, the FFG is selected as a representative ship for this analysis. Table 7 provides a list of broad baseline characteristics for the FFG class ship. The suite selected does not necessarily conform to the exact payload specified by an FFG but the areas presented are typical.

4.2.2. Proposed Ships

In order to assess the impact of different propulsion plants on the baseline ship, identical requirements are selected for the ships under consideration. Only those areas directly affecting the selected propulsion plants are changed.

4.3 Comparison of Ships

4.3.1 Gas Turbine

Table 8 summarizes the basic ships analyzed. The gas turbine powered ship displaces 3635 tons and requires 663.6 tons of fuel to go 4500 nautical miles with a maximum sustained speed of 30.45 knots. The

BROAD BASELINE CHARACTERISTICS FOR FFG7 CLASS

SPEED:	28+ KTS; Sustained 20 KTS
RANGE:	4500 N.M.
ENDURANCE:	60 Days
DISPLACEMENT:	4000 Tons (Max)
LENGTH:	410 FT. B.P.
BEAM:	42 FT.
DRAFT:	16 FT.
PROPULSION:	G.T. (LM2500)
KW:	4000 (M.S. Diesels)
WEAPONS:	2 - 76 MM Guns
	1 - Harpoon (Box of four)
	1 - ASROC Launcher
	2 - MK32 Torpedo Tubes
	2 - Lamps III Helos
	1 - MK13 Launcher
	2 - Redeye
RADAR:	SPS49, SPS55
FIRE CONTROL:	MK-74FCS, MK116 UBFCS
SONAR:	SQS 26(CX), Tactlass

TABLE 7

SUMMARY OF PROPULSION PLANTS

PLANT TYPE	DISPLACEMENT	VS.	FUEL	SPECIFIC PROPULSION WT.
Gas Turbine	3634.85	30.45	663.6	15.34
Feher Basic				
Model	3368.98	31.28	496.6	16.46
Modified	3515.61	30.77	504.3	21.27
Recompression				
Model	3523.57	30.75	484.0	22.03
Modified	3841.42	29.9	495.1	31.11

SHP = 40,000 ENDURANCE = 4500 N.M.

TABLE 8

specific propulsion weight (WTG2/SHP) is determined to be 15.34 Lbs. per shaft horsepower. A summary of the results of the baseline ship is given in Appendix II.

4.3.2 Basic Engine Model

Using the basic engine (model) to power the ship described in Table 7, a 7% savings in total ship size is achieved. In addition, the ship is capable of going .83 knots faster with a slightly heavier specific propulsion weight. Because of the improved specific fuel consumption of the basic engine, a 25.2% savings in fuel is achieved.

As given in Figure 24, for the same amount of fuel required for the baseline ship, the range of the vessel can be increased by 1250 nautical miles at approximately the same displacement. On the other hand, a slight decrease in sustained speed and an increase in weight group two are encountered as depicted in Figure 25. See Appendix II for a summary of results.

4.3.3 Basic Engine (Modified)

If the modified basic engine is adopted to reduce risk as discussed in Chapter 2, only a 3.3% savings in total ship size is experienced. Less than 1/3 knot is

Endurance vs. Displacement and Fuel
Basic Engine (Model)

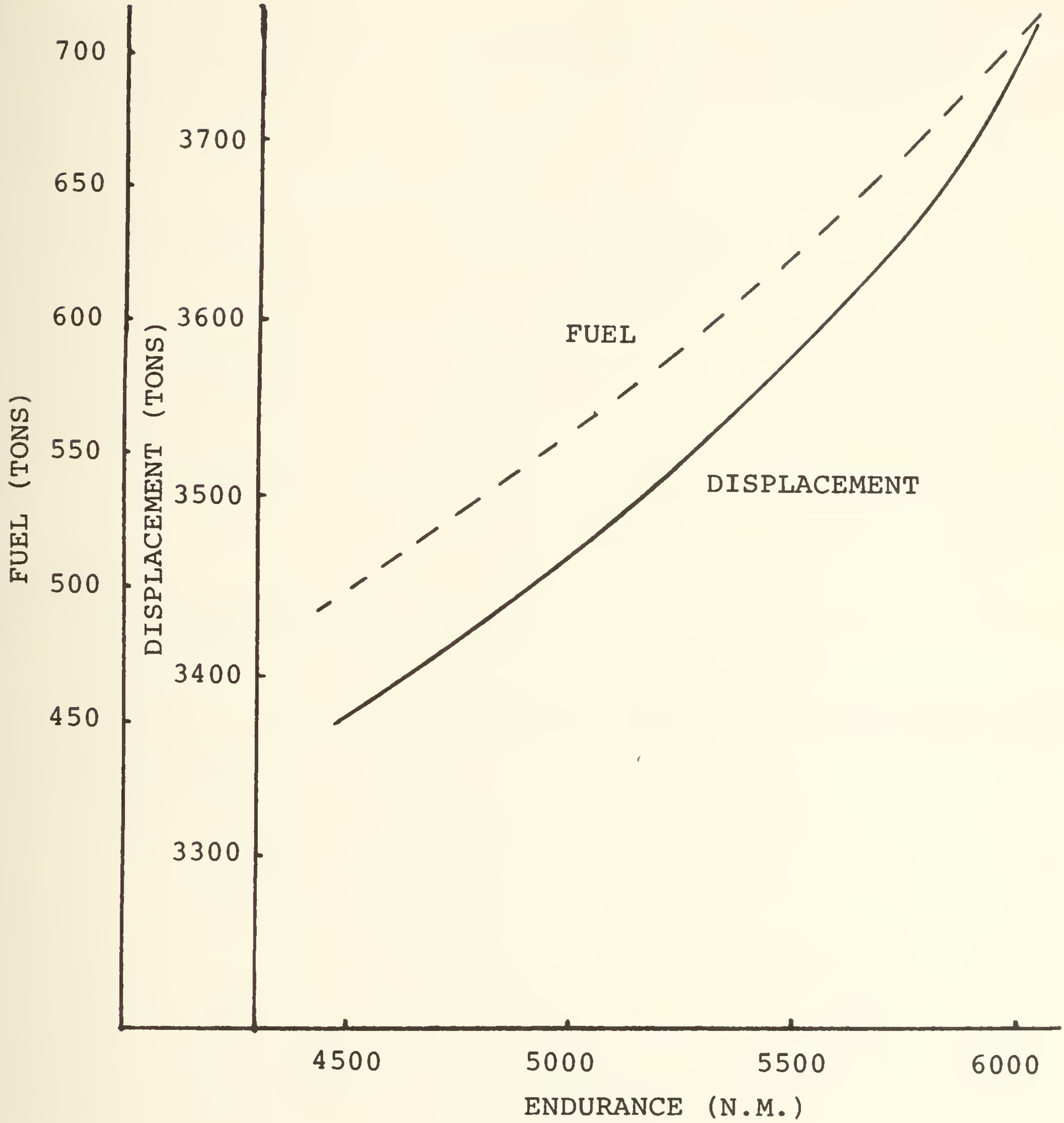


FIGURE 24

Endurance vs. Specific Propulsion Weight and Speed
Basic Engine (Model)

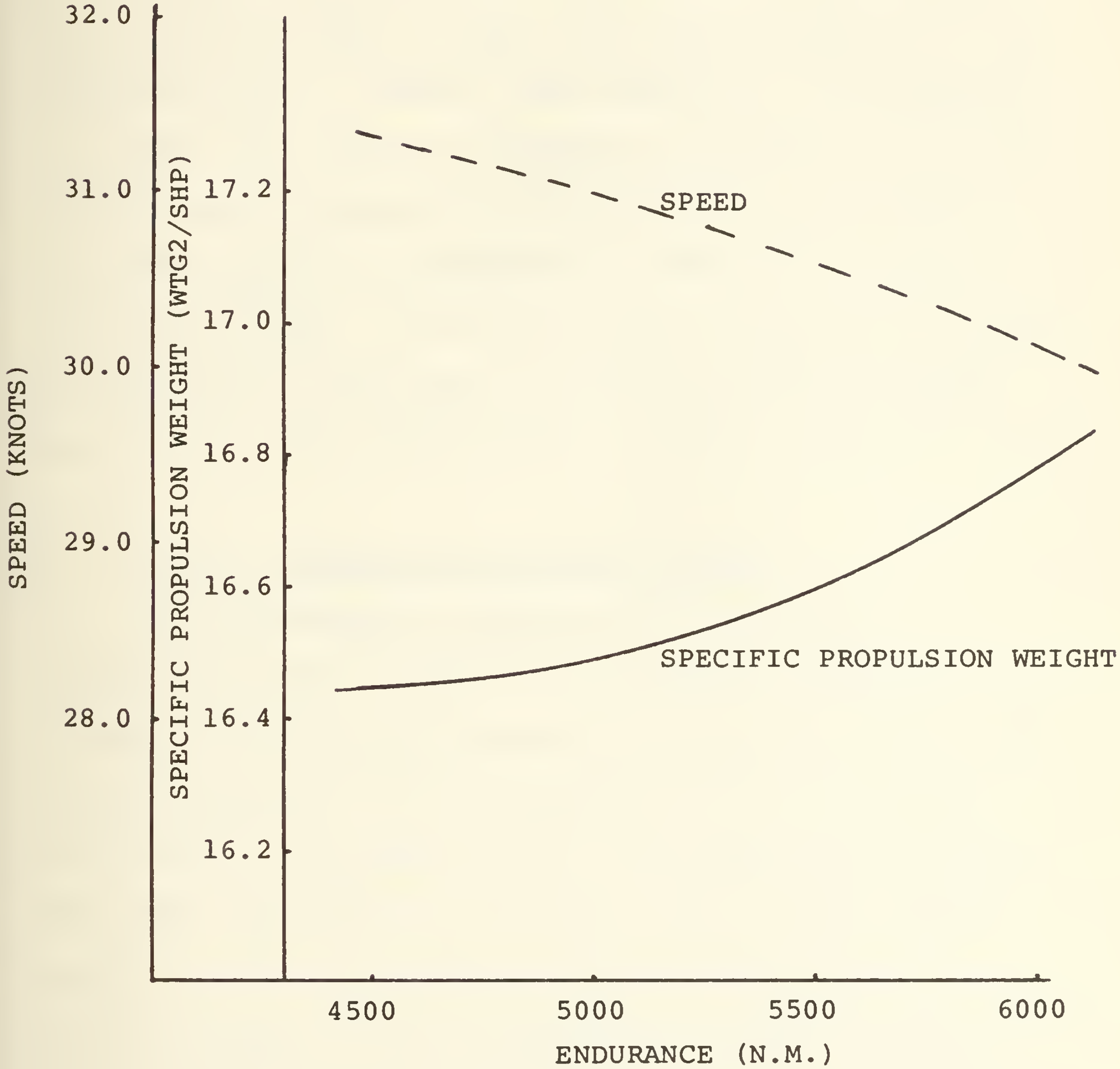


FIGURE 25

gained in sustained speed for a much heavier plant. On the other hand, a 24% savings in fuel is attained.

The endurance of the ship could be 5700 nautical miles on 663.4 tons of fuel (the amount required for the baseline ship). However, this requires a 5.2% increase in total ship size as illustrated in Figure 26. If the ship size was increased to 3634.85 tons, the frigate's endurance could be lengthened to 4950 N.M. and require 540 tons of fuel. The curves shown in Figure 27 indicate the effects of endurance on specific propulsion weight and speed. Ship calculations are given in Appendix II.

4.3.4. Recompression Engine (Model)

The recompression engine has a better fuel consumption than the basic or gas turbine engines. Table 7 indicates the increase in group two weight. The length and beam of the machinery box are increased to account for the added size of the recompression engine. The ship displaces 111 tons less than the gas turbine ship. A small increase in speed is obtained with a 27.1% savings in fuel as expected. Figures 28 and 29 give useful information on the effects of changing fuel or displacement.

Endurance vs. Displacement and Fuel
Basic Engine (Modified)

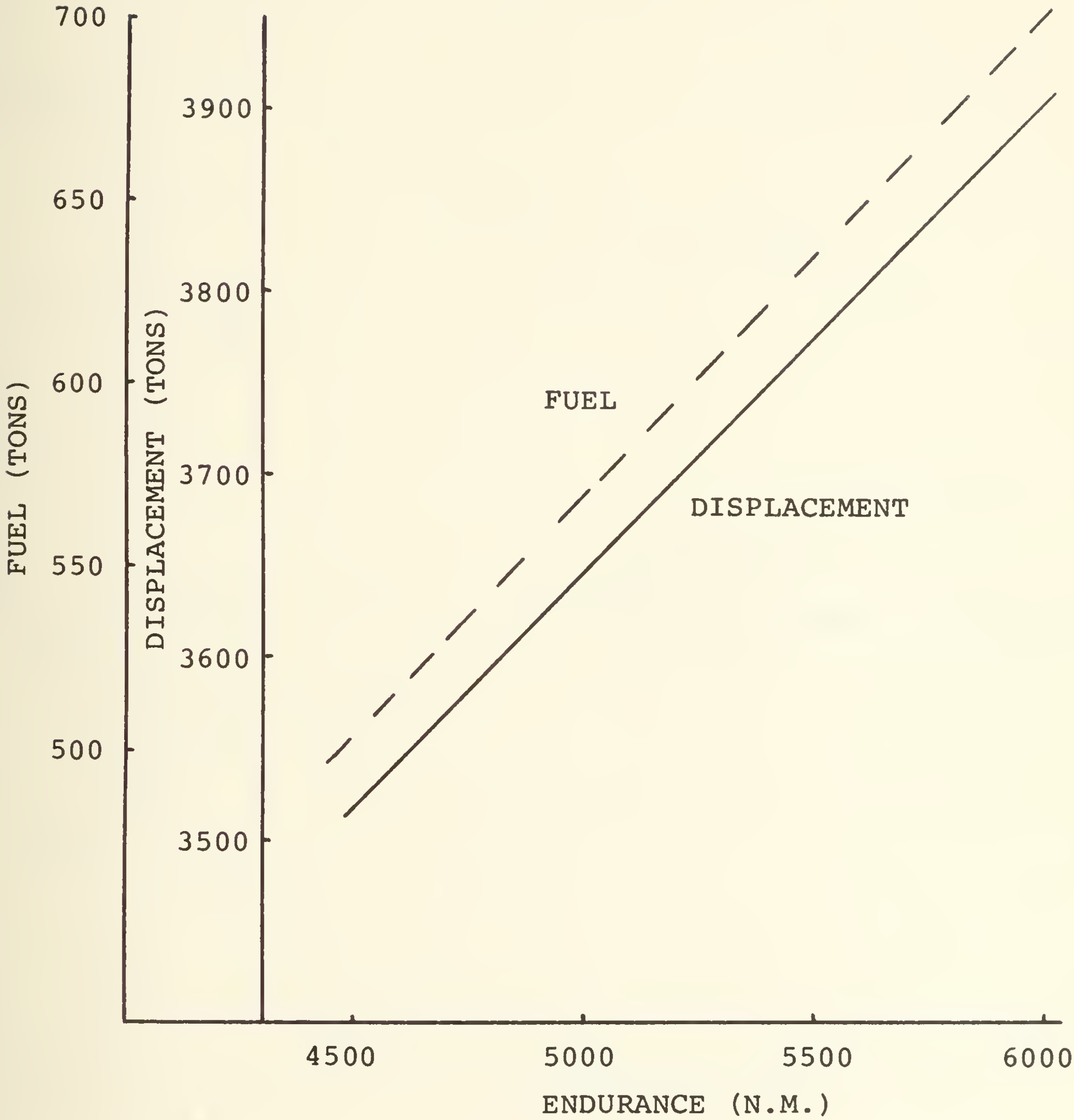


FIGURE 26

Endurance vs. Specific Propulsion Weight and Speed
Basic Engine (Modified)

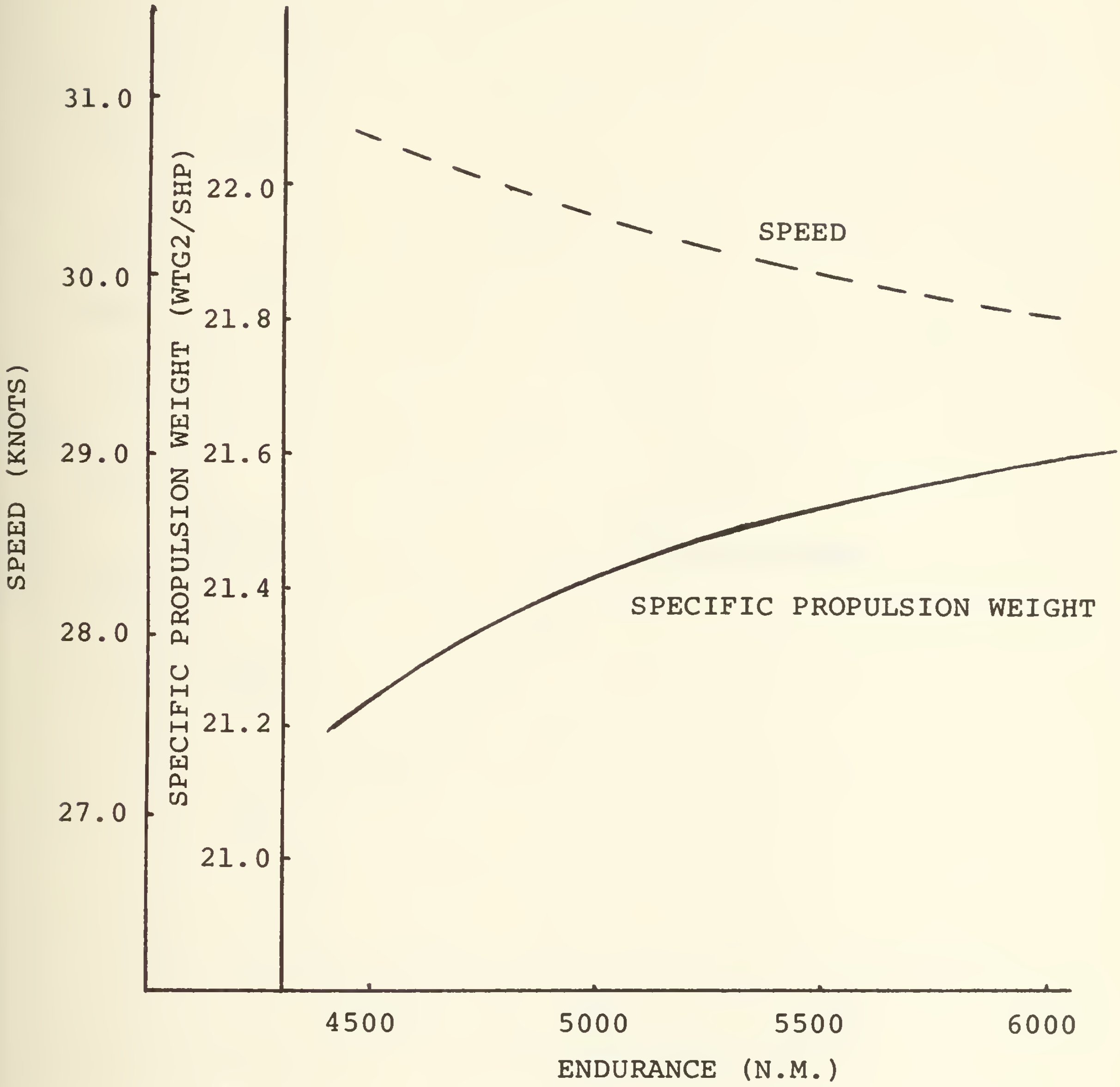


FIGURE 27

Endurance vs. Displacement and Fuel
Recompression (Model)

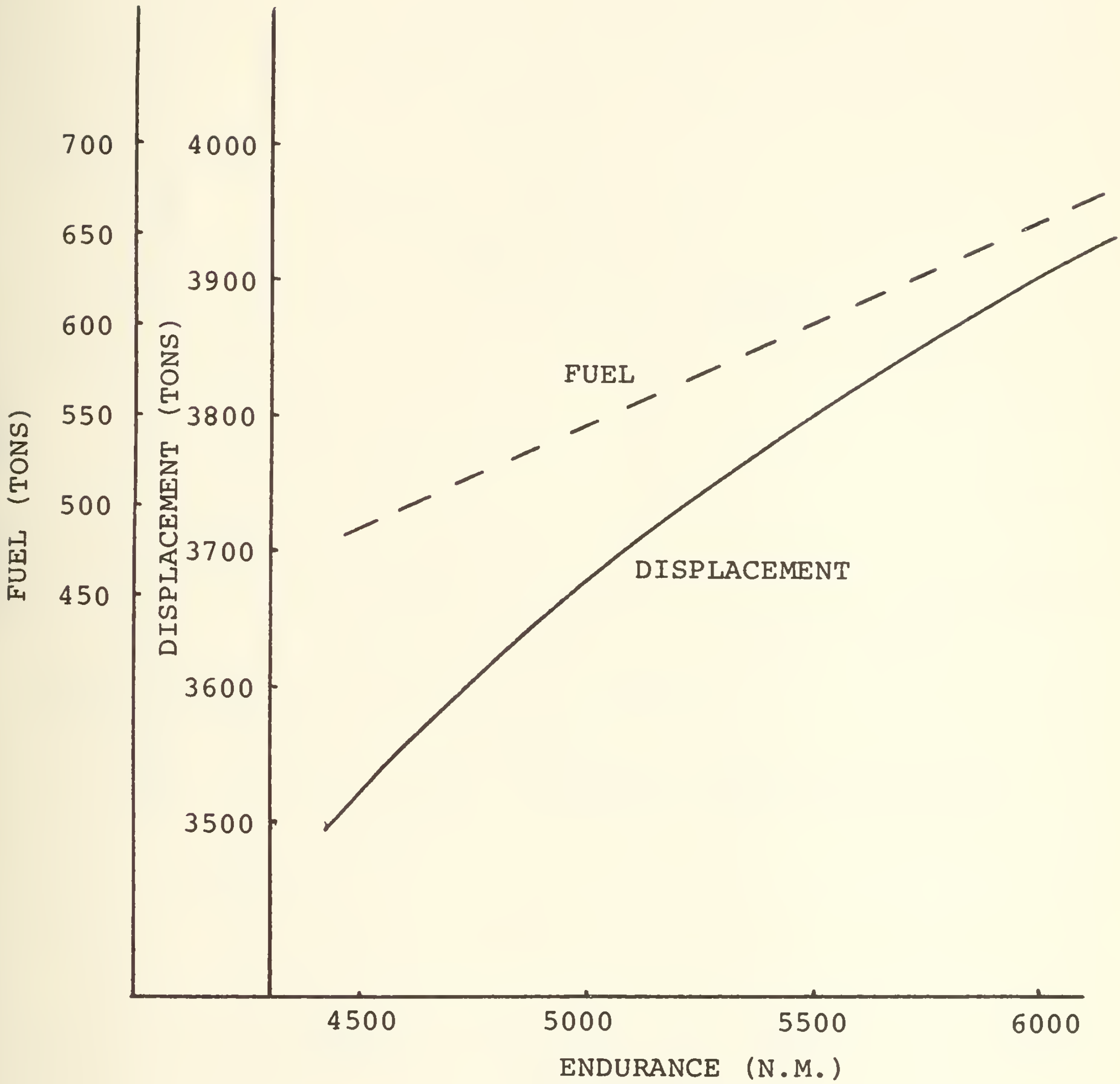


FIGURE 28

Endurance vs. Specific Propulsion Weight and Speed
Recompression (Model)

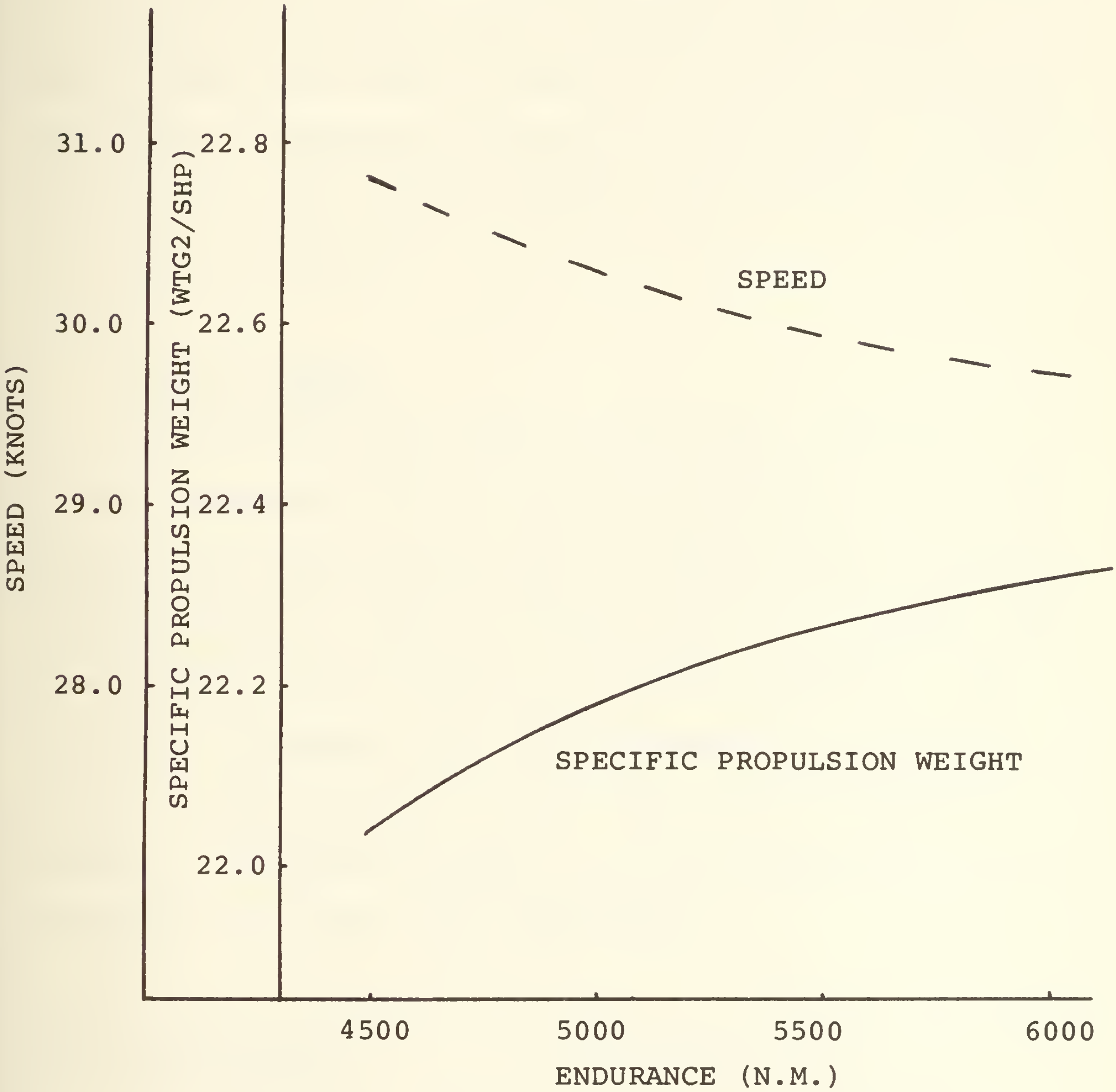


FIGURE 29

4.3.5 Recompression Engine

Table 7 shows that a 25.4% savings in fuel is brought about by a reasonable design of the recompression engine. On the other hand, the added weight of the plant causes the ship to grow by 5.7% and a 2% reduction in speed. Interesting variations in ship size, endurance, sustained speed, specific weight, and fuel are obtained in Figures 30 and 31.

4.3.6 General

To determine the impact of the Feher engine on shaft horsepower and full load displacement at different speeds, the basic model engine is compared with the gas turbine engine. Figure 32 shows that at low speeds, the gas turbine plant requires less shaft horsepower. But as speed increases, more shaft horsepower is required; thus, the Feher engine is more efficient at higher speeds. The same conclusion is drawn from Figure 33 in regards to the full load displacement.

4.4 Conclusions

In conclusion, the basic model, modified basic, model recompression, and modified recompression engines have been analyzed to determine their total ship impact.

Endurance vs. Displacement and Fuel
Recompression (Modified)

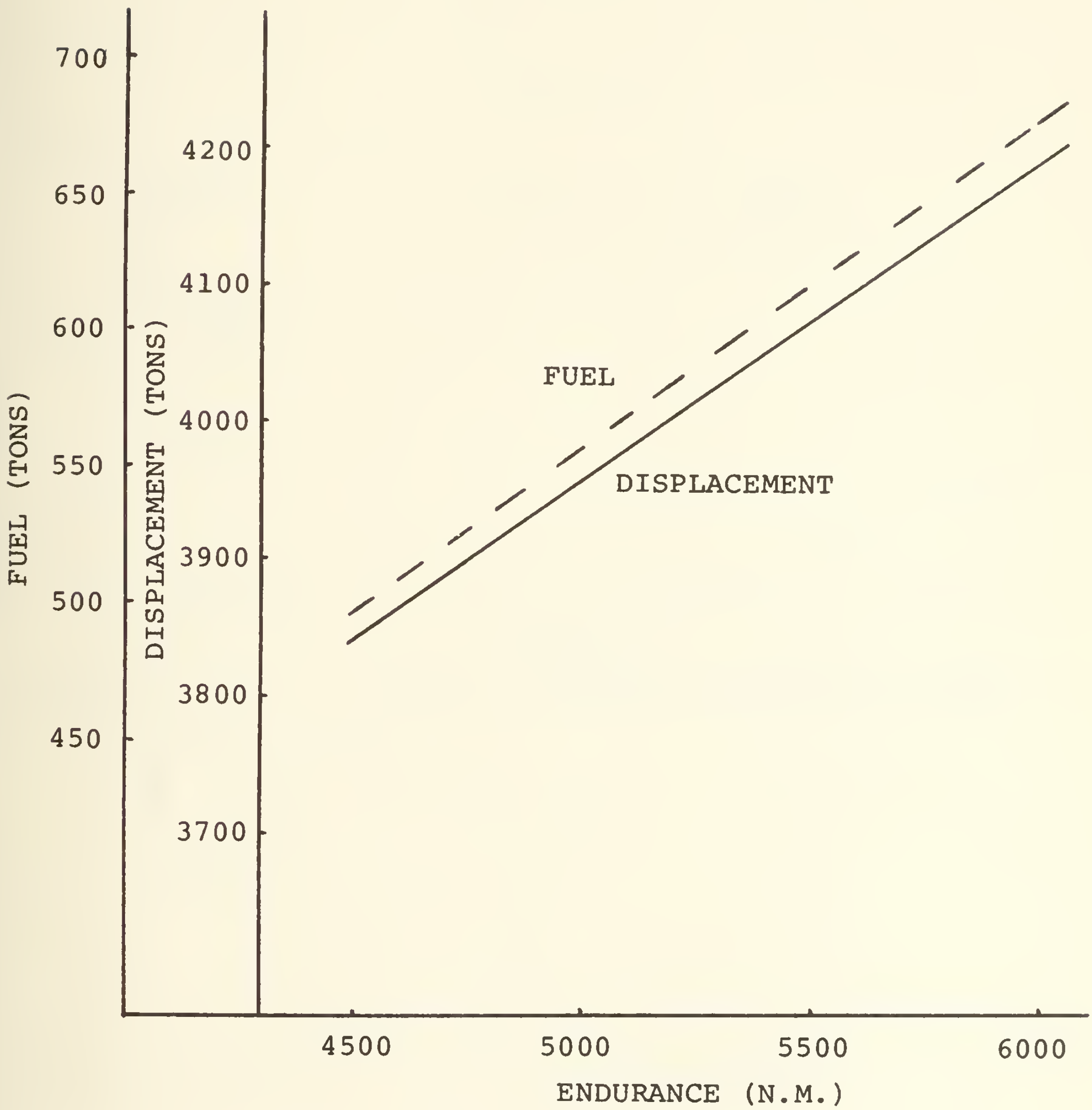


FIGURE 30

Endurance vs. Specific Propulsion Weight and Speed Recompression (Modified)

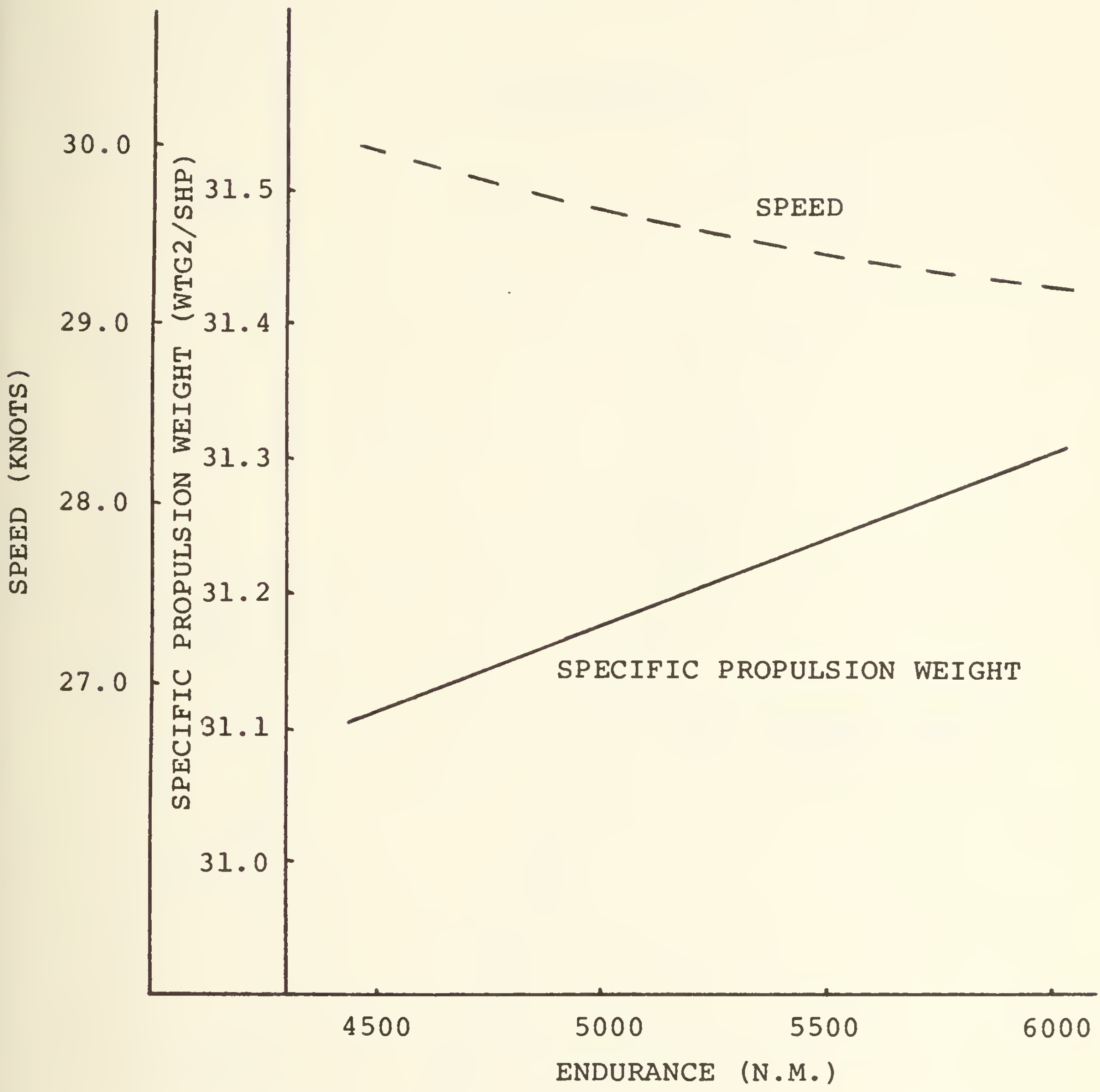


FIGURE 31

Shaft Horsepower vs. Speed

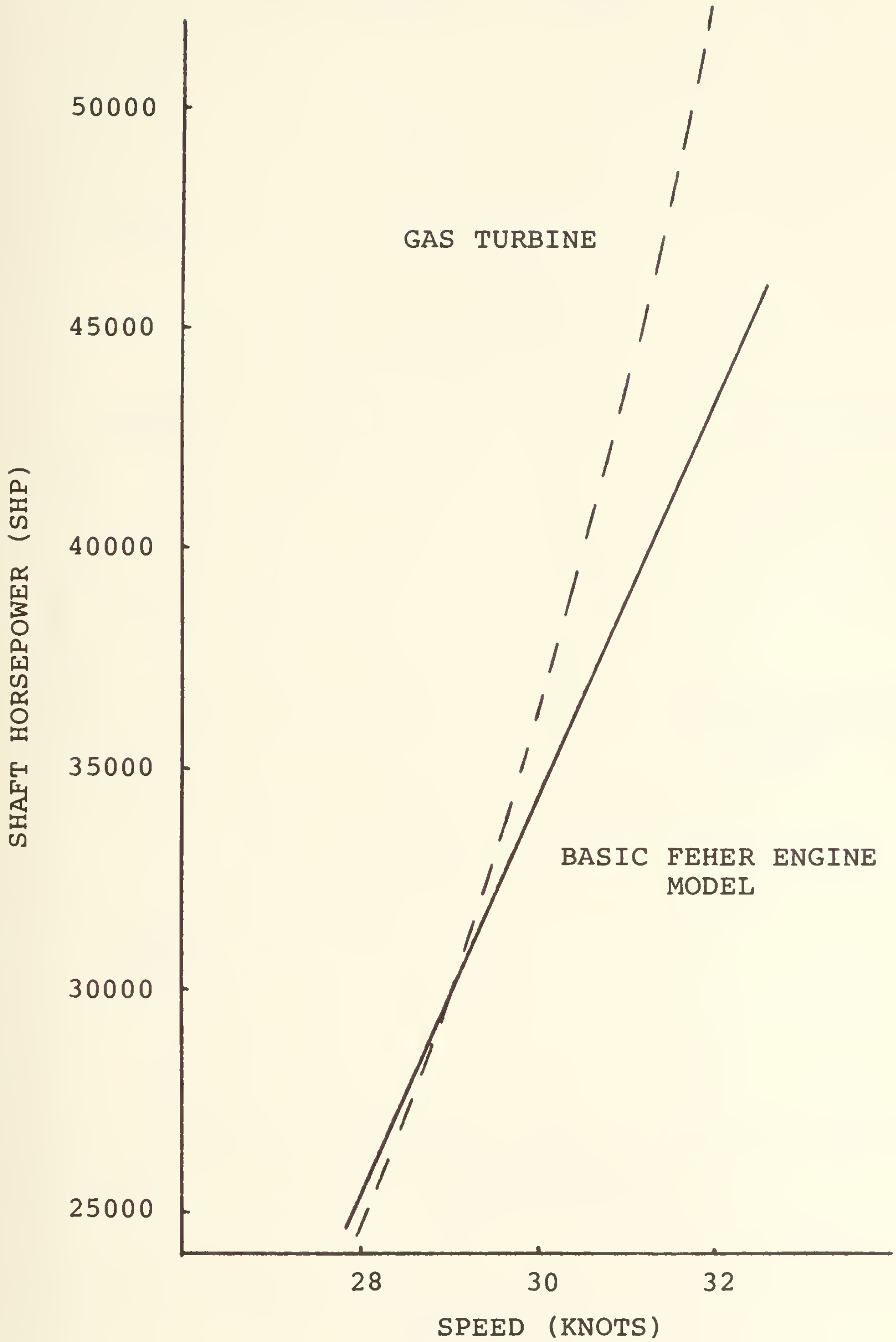


FIGURE 32

DISPLACEMENT VS. SPEED

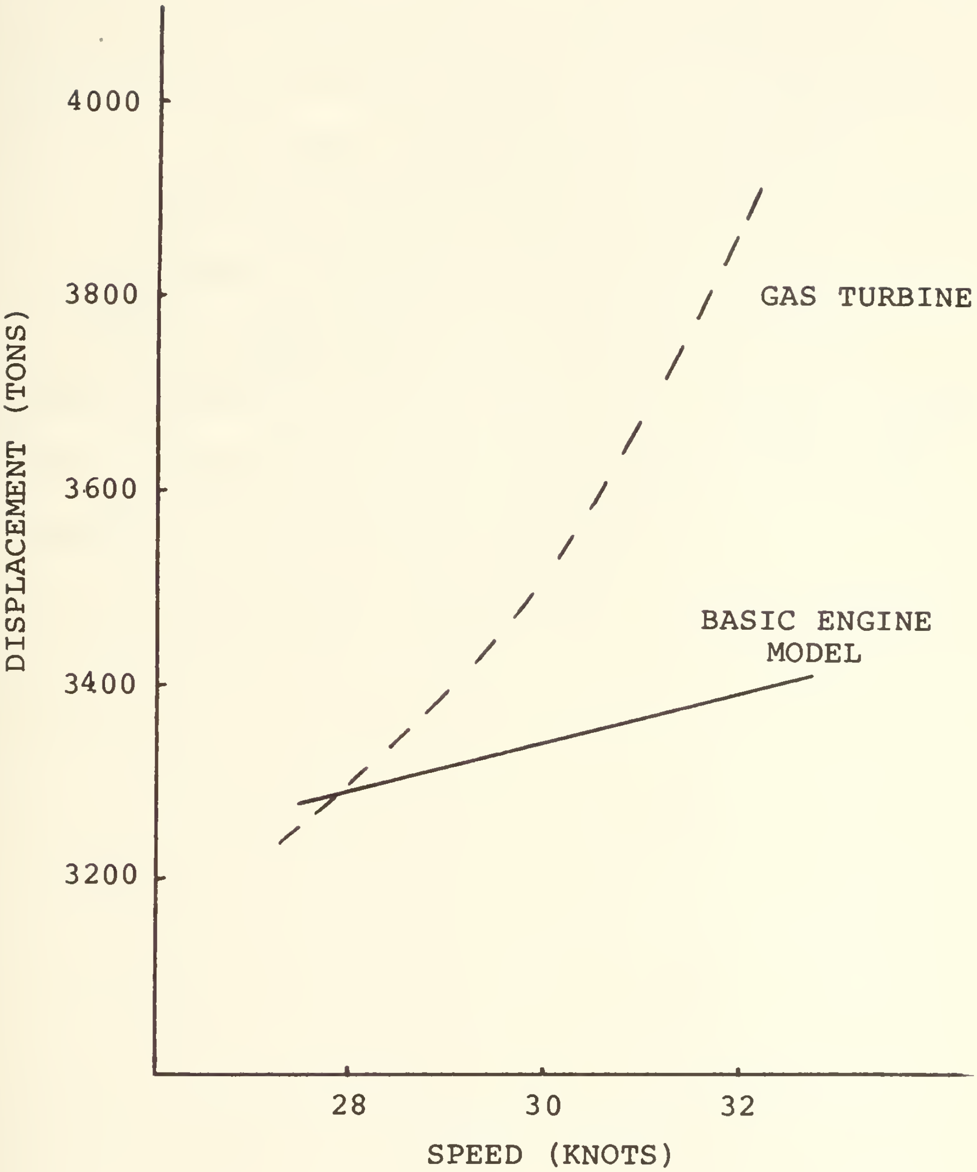


FIGURE 33

All four engines are considered appropriate for naval shipboard application with an expected amount of risk.

Each CO_2 engine shows a significant savings in fuel. However, when the "true cost" of the subsystem is considered, savings in fuel alone is not necessarily overwhelming. The naval architect must determine - through compromise or from design requirements - which plant is sufficient for the intended application.

It must be emphasized that system-engineering performance elements are not taken into account in this discussion. This vital area must be addressed by the ship designer prior to a plant selection.

CHAPTER 5

FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Summary of Findings

The current "energy crisis" highlights the need for innovation in fuel economy measures for new naval ship designs. These innovations must be consistent with the overall ship design philosophy for the ship and should be measured with the total-ship impact in mind.

One such innovation, the supercritical carbon dioxide engine, showed good promise for industrial applications. As the Navy attempts to emphasize low mix ships and increase its inventory of non-nuclear ships, an investigation into the feasibility of applying the supercritical cycle as a propulsion system is worthwhile.

The baseline ship for this study was a FFG 7 class frigate with gas turbine propulsion. Several alternatives were considered. First, the basic engine was analyzed and selected as the "model" engine since a conceptual study had been performed. Secondly, a recommended engine using larger tubes in the heat exchangers was examined. Thirdly, as the recompression engine showed more promise in saving fuel, it was also analyzed based on the tube sizes utilized in the basic model. The final engine was

a recompression engine with larger tubes.

Each engine demonstrated that at least a 24% savings in fuel could be realized. The basic engine (model) saved 25% fuel and was smaller than the baseline by 7%. The modified basic engine was smaller by 3.3% and saved 24% fuel. The recompression engine provided 27% savings in fuel for approximately the same displacement as the baseline ship. Although the modified recompression engine saved 25.4% fuel, the ship was heavier by 5.7% and speed was reduced by 2%.

The gas turbine plant required less horsepower at low speeds but gave way to the more efficient supercritical engine at higher speeds. In addition, the baseline ship displaced more weight at higher speeds.

5.2 Conclusions

The proposal of utilizing a supercritical carbon dioxide engine in a naval combatant is promising. There are significant increases in power or efficiency and they can be turned into worthwhile fuel savings, but the "true cost" to the ship system could conceivably offset any gains in fuel.

If fuel conservation and resource management become the dominant forces in ship design philosophy, the ship

designer could consider the use of the supercritical engines, as long as factors such as risk, development cost, and operational constraints are properly examined.

5.3 Recommendations for Future Work

The original assumption in this study was to limit the analysis to architectural requirements as they pertain to operational performance in order to investigate the potential of the supercritical carbon dioxide cycle in naval ship application. The power plants have shown significant savings in fuel based on operational performance and that a more detailed analysis of the systems-engineering performance factors should be completed to give a more comprehensive analysis. In addition, the "monetary cost" of the subsystem should be evaluated to measure its cost-effectiveness.

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NOMENCLATURE USED IN TEXT

AVEDPW	average endurance power, horsepower
B.P.	between perpendiculars
CO2	carbon dioxide
EDPWPE	power required per engine at endurance speed, horsepower
°F	temperature degrees Fahrenheit
FT	feet
G.T.	gas turbine
h	specific enthalpy (BTU/Lbm)
KTS	knots
KW	kilowatts
LHV	lower heating value
$\dot{m}$	mass flow rate (Lbm/Hr)
M.S.	medium speed
NE	number of engines installed
NM	nautical miles
$\dot{Q}$	heat transfer rate (BTU/Hr)
RPM	revolutions per minute
SFC	specific fuel consumption ($\dot{m}_f$/SHP)
SFCAED	average endurance specific fuel consumption Lbm/SHP•HR
SFCFP	full power specific fuel consumption Lbm/SHP•HR
SHP	shaft horsepower

VS	sustained speed
$\dot{W}$	rate of output shaft work (BTU/HR)
W(112)	weight of propulsion foundations
W(204)	weight of combustion air supply
W(205)	weight of uptakes and smoke pipes
WTG2	weight group two
η	thermal efficiency
%	percentage
"	inch

Subscripts

c	compressor
cycle	cycle
f	fuel
net	net
p	pump
T	turbine

APPENDIX I-A

NOMENCLATURE FOR MAIN PROGRAM

A	total heat transfer area, ft^2
AIR	subroutine for air preheater properties as appropriate
AIRH	subroutine for combustor CO_2 properties as appropriate
AL	length of tubes, ft.
ALI	total length of core
ALOA	length overall
AN	total number of tubes
CO2C	subroutine for cooler CO_2 properties as appropriate
CO2H	subroutine for combustor CO_2 (recompression) properties as appropriate
CO2R	subroutine for recuperator properties as appropriate
COMBS1	subroutine for combustor CO_2 properties
COMBS2	subroutine for combustion properties
COOL1	subroutine for cooler properties (recompression)
CV,P	specific heat, BTU/Lbm-F
D	heat exchanger diameter, ft.
DO	outside diameter, ft.
D1	inside diameter, ft.
D2	hydraulic diameter, ft.
D1IN	inside diameter, in.

DOIN	outside diameter, in.
DF	design factor
DI	inside diameter, in.
DPC	difference in cold pressure
DPH	difference in hot pressure
DPSS	diameter pipe, shell side
DPTS	diameter pipe, tube side
DTA,B,C,H	temperature difference
DTLM	log mean temperature
EFF	heat exchanger effectiveness
F	factor of safety, 1.5
F1	$L \times \rho_1 \times N_T \times N_u$
F2	$L \times \rho_2 \times N_T \times N_u$
G	gravity, 32.17 ft/sec^2
G1,2	mass flow rate
H	enthalpy, BTU/Lbm
HEAT	heat transfer
HELIUM	subroutine for helium properties
KFC	KFC=1 cold fluid in tubes; 2 in shell
K	index value
K1,2	constants for heat exchanger calculations
M1,2	Mach number
N	number of tubes
NIN	number of heat exchangers calculated

NU	number of units
P	absolute difference in pressure
PBARC,H	average pressure
PCI,H	inlet pressure
PD	pressure
PHEAT	subroutine for preheater properties
PI	3.141593
PITCH	center to center spacing between tubes
PR	Prandtl number
Q	constant, defined in program
RCP1	subroutine for low temperature recuperator properties
RCP2	subroutine for high temperature recuperator properties
RE	Reynolds number
RHO	density, Lbm/cu-ft.
RSC	resistance scale factor for salt water
S	entropy, BTU/(Lb-°R)
SIG	yield stress, Lbf/in^2
SQR3	square root of 3 -- 1.732051
SWGHT	total system weight, Lbs
SWATER	subroutine for cooler properties
T	temperature, °R
TBARC,H	average temperature, °R
TCI,O	temperature of cold side (in,out)

TEB	thickness of end bell
THI,O	temperature of hot side (in,out)
TK	thermal conductivity, BTU/HR FT °F
TPPS	pipe thickness, shell side, ft.
TPSSIN	pipe thickness, shell side, in.
TPTS	pipe thickness, tube side, ft.
TPTSIN	pipe thickness, tube side, in.
TSH	thickness of shell
TT	thickness of tube, in.
TTS	thickness of tube sheet, in.
TWGHT	total system weight, tons
U1	overall coefficient of heat transfer
VOL	volume of heat exchanger
VS	speed of sound
WATH	weight of fluid in heaters, lbs.
WATSH	weight of fluid shell side, lbs.
WATT	weight fluid in tubes, lbs.
WEB	weight of end bell, lbs.
WEIGHT	total system weight, lbs.
WGHT	weight of heat exchanger, core
WFINHX	weight fluid in heat exchanger, lbs.
WH,C	flow rate, BTU/HR
WIPSS	weight of fluid in pipe shell side, lbs/ft.
WIPTS	weight of fluid in pipe tube side, lbs/ft.

WPSS	weight of pipe/ft shell side, lbs/ft.
WPTS	weight of pipe/ft tube side, lbs/ft.
WSHELL	weight of shell

APPENDIX I-B

NOMENCLATURE FOR SUBROUTINES LISTING

A	0.06310 cu-ft/lb
B	0.0005342 cu-ft/(lb-°R$^{1/2}$)
CK	thermal conductivity, BTU/hr-ft-°R
CP	specific heat at constant pressure, BTU/lb-°R
CPO	specific heat ideal state, BTU/lb-°R
CV	specific heat at constant volume, BTU/lb-°R
GO	gravity (-32.1667), ft/sec^2
H	enthalpy, BTU/lb
HO	reference enthalpy, BTU/lb
P	pressure, psia
PO	reference pressure, 14.696 psia
PR	Prandtl number
R	gas constant (2.68111) psia-cu-ft/(lb-°R)
RHO	density, lb/ft^3
S	entropy, BTU/lb-°R
T	temperature, °R
TO	reference temperature, 450°R
V	specific volume, cu-ft/lb
VI	viscosity
VS	sonic velocity, ft/sec

APPENDIX I-C

NOMENCLATURE FOR SHIP OUTPUT

AVSEASPD	average sea speed
B/H	beam to draft ratio
BATTLEKW	battle load electrical power
CP	prismatic coefficient
CRUISE KW	cruising load electrical power
Cx	midship section coefficient
DO	depth at forward perpendicular, ft.
D1O	depth at amidships, ft.
D2O	depth at after perpendicular, ft.
DAVG	average hull depth, ft.
DISP FLD	full load displacement, tons
DISP LSP	light ship displacement, tons
END SHP	endurance shaft horsepower, SHP
EXCESS KG	excess height of the center of gravity, ft.
FLD DENS	design indice
KW 24 AV	24 hour average electric load, kw.
KW/DIESL	KW per diesel plant
KW/EMERG	KW per emergency plant
KW/GAST	KW per gas turbine generator installed
KW INST	total installed ship service and emergency electric capacity, KW
KWIN/FLD	installed electric power per displacement KW/ton

KW SPSER	total ship service electric capacity installed, KW
KW/STMG	KW per steam turbine generator installed, KW
L/B	length to beam ratio
LEN R DK	length between perpendiculars of raised deck, ft.
LBP	length between perpendiculars
LSP DENS	density
MEN/DISP	number of men per full load displacement
NU ACCOM	number of personnel
NU LOWSD	number of low speed diesel generators installed
NU MEDSD	number of medium speed diesel generators installed
NU HISD	number of high speed diesel generators installed
NU GT GN	number of gas turbine generators installed
NU ST GN	number of steam turbine generators installed
RANGE	endurance, nautical miles
SHP/DISP	shaft horsepower per full load displacement
SUS SHP	shaft horsepower required at maximum sustained speed
VCG/DAVG	vertical center of gravity per average hull depth
VCG FLD	center of gravity
VEND	speed at endurance
VHAP/MAN	volume of habitability per man

VMB/SHP	volume of machinery box per shaft horsepower
VOL HULL	volume in hull
VOL SSTR	volume in superstructure
VOL TOT	total volume
VOPS/VOL	volume of operations per total volume (operation density)
VPAY/VOL	volume of payload per total volume (payload density)
VPER/VOL	volume required by personnel per total volume (personnel density)
VR LOADS	variable loss
VSUS	sustained speed, kts.
WHAB/MAN	weight of habitability per man
WOPS/FLD	weight of operations per full load displacement (operations weight fraction)
WPAY/FLD	weight of payload per full load displacement (payload weight fraction)
WPER/FLD	weight of personnel items per full load displacement (personnel weight fraction)
WTGRP1	weight group one
WTGRP2	weight group two
WTGRP3	weight group three
WTGRP4	weight group four
WTGRP5	weight group five
WTGRP6	weight group six
WTGRP7	weight group seven
WT MARG	weight margin

WTG2/SHP	weight group two per shaft horsepower
WTG3/KWIN	weight group three per installed KW
WTG1/VOL	weight group one per total volume
WTG5/VOL	weight group five per total volume

APPENDIX II

HEAT EXCHANGER PROGRAM

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$JOB

      THIS COMPUTER PROGRAM CALCULATES HEAT EXCHANGERS



      COMMON T(20),RHOW(20),CPW(20),VISW(20),TKW(20)
      REAL*4 K1,K2,K3,K4,K5,K6,K7,K8,K9,K10,K11,K12
      REAL*4 M1,M2
      DATA G,PI,SQR3 / 32.17, 3.141593 , 1.732051 /
      DATA RHOS,SIG ,F / 499.33, 20000., 1.5 /
      DATA RHOCN,SIGA/558.0,35000./
      DATA RSC / .0005 /
      DF=1.0
      DO 500 J=1,20
  500 READ(5,501) T(J),RHOW(J),CPW(J),VISW(J),TKW(J)
  501 FORMAT(3F10.4,2E15.4)
      READ(5,110) NIN
  110 FORMAT(I5)
      DO 50 I=1,NIN
      READ(5,100) THI,THO,TCI,TCO,PHI,PCI
  100 FORMAT(6F10.2)
      READ(5,101) NU,DPH,DPC,DI,DO,PITCH
  101 FORMAT(I10,5F10.4)
      READ(5,102) WH,WC,KFC,K
  102 FORMAT(2F10.4,2I10)
      Q=(2.*SQR3/PI*(PITCH/DO)**2-1.)
      DOTS=DO/PITCH
      D1IN=DI
      DOIN=DO
      D1=DI/12.
      DO=DO/12.
      D2=Q*DO
      DTH=THI-THO
   51 DTC=TCO-TCI
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      DTA=THI-TCO                                                       PGM10037
      DTB=THO-TCI                                                       PGM10038
      IF((K.EQ.6).OR.(K.EQ.11)) DTA=THI-TCI                             PGM10039
      IF((K.EQ.6).OR.(K.EQ.11)) DTB=THO-TCO                             PGM10040
   17 WRITE(6,200) THI,THO,TCI,TCO,PHI,PCI                              PGM10041
  200 FORMAT('1',6F15.4)                                                PGM10042
      WRITE(6,201) NU,DPH,DPC,DI,DOIN,PITCH                             PGM10043
  201 FORMAT(' ',I15,5F15.4)                                            PGM10044
      WRITE(6,202) WH,WC,KFC                                            PGM10045
  202 FORMAT(' ',2F15.4,I15)                                            PGM10046
      IF((DTA-DTB).LT.1.) GO TO 15                                      PGM10047
      DTLM=(DTA-DTB)/(ALOG(DTA/DTB))                                    PGM10048
      GO TO 16                                                          PGM10049
   15 DTLM=DTA                                                          PGM10050
   16 TBARH=(THI+THO)/2.                                                PGM10051
      PBARH=PHI-DPH/2.                                                  PGM10052
      TBARC=(TCI+TCO)/2.                                                PGM10053
      PBARC=PCI-DPC/2.                                                  PGM10054
      GO TO (75,76,77,78,79,90,91,92,93,94,95,96), K                    PGM10055
   75 EFF=DTC/(THI-TCI)                                                 PGM10056
      CALL HELIUM(TBARH,PBARH,HH,RHOH,CVH,CPH,VSH,CKH,VIH,SH,PRH)       PGM10057
    1 CALL HELIUM(TBARC,PBARC,HC,RHOC,CVC,CPC,VSC,CKC,VIC,SC,PPC)       PGM10058
      GO TO 5                                                           PGM10059
   76 EFF=DTH/(THI-TCI)                                                 PGM10060
      CALL WATER(TBARC,RHOC,CPC,VIC,CKC,PRC)                            PGM10061
      CALL HELIUM(TBARH,PBARH,HH,RHOH,CVH,CPH,VSH,CKH,VIH,SH,PRH)       PGM10062
      WC=(EFF*WH*CPH*(THI-TCI))/((TCO-TCI)*CPC)                         PGM10063
      VSC=1.E+20                                                        PGM10064
      GO TO 5                                                           PGM10065
   77 EFF=DTH/(THI-TCI)                                                 PGM10066
      CALL  WATER(TBARC,RHOC,CPC,VIC,CKC,PRC)                           PGM10067
      CALL WATER(TBARH,RHOH,CPH,VIH,CKH,PRH)                            PGM10068
      WC=(EFF*WH*CPH*(THI-TCI))/((TCO-TCI)*CPC)                         PGM10069
      VSC=1.E+20                                                        PGM10070
      VSH=1.E+20                                                        PGM10071
   78 CALL CO2R1(RHOC,CPC,CKC,VIC,PPC,VSC)                              PGM10072
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      CALL CO2R2(RHOH,CPH,CKH,VIH,PRH,VSH)                          PGM10073
      GO TO 5                                                       PGM10074
   79 CALL AIR2(RHOC,CPC,CKC,VIC,PRC,VSC)                           PGM10075
      CALL AIR1(RHOH,CPH,CKH,VIH,PRH,VSH)                           PGM10076
      EFF=DTH/(THI-TCI)                                             PGM10077
      WC=(EFF*WH*CPH*(THI-TCI))/((TCO-TCI)*CPC)                     PGM10078
      GO TO 5                                                       PGM10079
   90 CALL CO2H1(RHOC,CPC,CKC,VIC,PRC,VSC)                          PGM10080
      CALL AIRH2(RHOH,CPH,CKH,VIH,PRH,VSH)                          PGM10081
      GO TO 5                                                       PGM10082
   91 CALL CO2C(RHOH,CPH,CKH,VIH,PRH,VSH)                           PGM10083
      CALL SWATER(TBARC,RHOC,CPC,VIC,CKC,PRC)                       PGM10084
      VSC=1.E+20                                                    PGM10085
      GO TO 5                                                       PGM10086
   92 CALL RCP11(RHOC,CPC,CKC,VIC,PRC,VSC)                          PGM10087
      CALL RCP12(RHOH,CPH,CKH,VIH,PRH,VSH)                          PGM10088
      GO TO 5                                                       PGM10089
   93 CALL RCP21(RHOC,CPC,CKC,VIC,PRC,VSC)                          PGM10090
      CALL RCP22(RHOH,CPH,CKH,VIH,PRH,VSH)                          PGM10091
      GO TO 5                                                       PGM10092
   94 CALL COOL1(RHOH,CPH,CKH,VIH,PRH,VSH)                          PGM10093
      CALL SWATER(TBARC,RHOC,CPC,VIC,CKC,PRC)                       PGM10094
      VSC=1.E+20                                                    PGM10095
      GO TO 5                                                       PGM10096
   95 CALL COMBS1(RHOC,CPC,CKC,VIC,PRC,VSC)                         PGM10097
      CALL COMBS2(RHOH,CPH,CKH,VIH,PRH,VSH)                         PGM10098
      GO TO 5                                                       PGM10099
   96 CALL PHEAT1(RHOC,CPC,CKC,VIC,PRC,VSC)                         PGM10100
      CALL PHEAT2(RHOH,CPH,CKH,VIH,PRH,VSH)                         PGM10101
      EFF=DTH/(THI-TCI)                                             PGM10102
      WC=(EFF*WH*CPH*(THI-TCI))/((TCO-TCI)*CPC)                     PGM10103
      GO TO 5                                                       PGM10104
    5 GO TO (10,20),KPC                                             PGM10105
   10 W1=WC                                                         PGM10106
      DT1=DTC                                                       PGM10107
      DP1=DPC                                                       PGM10108
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      RHO1=RHOC                                                         PGM10109
      CP1=CPC                                                           PGM10110
      VS1=VSC                                                           PGM10111
      CK1=CKC                                                           PGM10112
      VI1=VIC                                                           PGM10113
      PR1=PRC                                                           PGM10114
      W2=WH                                                             PGM10115
      DT2=DTH                                                           PGM10116
      DP2=DPH                                                           PGM10117
      RHO2=RHOH                                                         PGM10118
      CP2=CPH                                                           PGM10119
      VS2=VSH                                                           PGM10120
      CK2=CKH                                                           PGM10121
      VI2=VIH                                                           PGM10122
      PR2=PRH                                                           PGM10123
      GO TO 30                                                          PGM10124
   20 W1=WH                                                             PGM10125
      DT1=DTH                                                           PGM10126
      DP1=DPH                                                           PGM10127
      RHO1=RHOH                                                         PGM10128
      CP1=CPH                                                           PGM10129
      VS1=VSH                                                           PGM10130
      CK1=CKH                                                           PGM10131
      VI1=VIH                                                           PGM10132
      PR1=PRH                                                           PGM10133
      W2=WC                                                             PGM10134
      DT2=DTC                                                           PGM10135
      DP2=DPC                                                           PGM10136
      RHO2=RHOC                                                         PGM10137
      CP2=CPC                                                           PGM10138
      VS2=VSC                                                           PGM10139
      CK2=CKC                                                           PGM10140
      VI2=VIC                                                           PGM10141
      PR2=PRH                                                           PGM10142
   30 K1=(.092*(VI1**.2))/(G*RHO1)                                      PGM10143
      K2=(.092*(VI2**.2))/(G*RHO2)                                      PGM10144
```

```
      K3=(.023*CK1*(PR1**.4))/(VI1**.8)                                PGM10145
      K4=(.023*CK2*(PR2**.4))/(VI2**.8)                                PGM10146
   80 W1U=W1/FLOAT(NU)                                                 PGM10147
      W2U=W2/FLOAT(NU)                                                 PGM10148
      G1G2=(W1U/W2U)*D2*DO/(D1**2)                                     PGM10149
      K5=K1/K2*((G1G2)**1.8)*((D2/D1)**1.2)                            PGM10150
      IF(DP1.LT. .001)  DP1=K5*DP2                                     PGM10151
      IF(DP2.LT. .001)  DP2=DP1/K5                                     PGM10152
      K6=G1G2                                                          PGM10153
      K7=(K3/K4)*((K2*K5/K1)**(1./3.))*((DO/D1)**.2)*((W1U/W2U)**.2)   PGM10154
      K9=CP1*DT1/(4.*DTLM)                                             PGM10155
      K8=(1./K3)*(1.+(D1/DO)*K7)*DF                                    PGM10156
      G10=0.0                                                          PGM10157
      GO TO 27                                                         PGM10158
  271 K8=((1./K3)*(1.+(D1/DO)*K7)+RSC*(G1**.8)/D1**2)*DF               PGM10159
   27 K10=SQRT((DP1*144.)/(K1*K8*K9))                                  PGM10160
      G1=K10                                                           PGM10161
      GO TO (272,272,273,272,272,272,272,272,272,272,272,272), K       PGM10162
  273 IF(((G1-G10)/G1).LT. .01) GO TO 272                              PGM10163
      G10=G1                                                           PGM10164
      GO TO 271                                                        PGM10165
  272 AL=K9*K8*(D1**1.2)*(G1**.2)                                      PGM10166
      K11=(W1U*4.)/(K10*PI)                                            PGM10167
      AN=K11/(D1**2)                                                   PGM10168
   81 N=IFIX(AN)                                                       PGM10169
      K12=PI*K8*K9*(K10**.2)*K11                                       PGM10170
      A=K12*(D1**.2)                                                   PGM10171
      U1=((G1**.8)/(K8*D1**.2))*3600.                                  PGM10172
   40 RE1=D1*G1/VI1                                                    PGM10173
      RE2=D2*G1/(VI2*G1G2)                                             PGM10174
      D=DO*SQRT(AN*(1.+O))                                             PGM10175
      AREA=PI*(D**2)/4.                                                PGM10176
      APRIM=PI*(8.0**2)/4.                                             PGM10177
      IF((K.EQ.5).OR.(K.EQ.12))APRIM=PI*(6.**2)/4.                     PGM10178
      AT=AREA+APRIM                                                    PGM10179
      IF((K.EQ.5).OR.(K.EQ.6).OR.(K.EQ.11).OR.(K.EQ.12))D=SQRT(4.*AT/PI) PGM10180
```

```
      VOL=(AL*PI*(D**2)/4.)*FLOAT(NU)                                   PGM10181
      HEAT=U1*A*DTLM*FLOAT(NU)*1.05435E-03/3600.                        PGM10182
      V1=G1/RHO1                                                        PGM10183
      M1=V1/VS1                                                         PGM10184
      V2=(G1/G1G2)/RHO2                                                 PGM10185
      M2=V2/VS2                                                         PGM10186
      PD=PHI                                                            PGM10187
      IF(KFC.EQ.2) PD=PCI                                               PGM10188
  111 PD=F*PD                                                           PGM10189
      IF((K.EQ.5).OR.(K.EQ.6).OR.(K.EQ.11).OR.(K.EQ.12))SIG=SIGA        PGM10190
      IF((K.EQ.7).OR.(K.EQ.10)) RHOS=RHOCN                              PGM10191
  112 TSH=(PD*D)/(2.*SIG)                                               PGM10192
      IF(TSH*12..LT..5) TSH=.5/12.                                      PGM10193
      Y=10.*DOTS+1.                                                     PGM10194
      X=13.*(1.-(Y/10.)**2.8)*(1./2.8)                                  PGM10195
      W=-.5*X+8.5                                                       PGM10196
      P=ABS(PHI-PCI)                                                    PGM10197
      IF(P.LT.5.) P=PHI                                                 PGM10198
      IF((K.EQ.5).OR.(K.EQ.6).OR.(K.EQ.11).OR.(K.EQ.12))D=DO*SQRT(AN*(1.PGM10199
     1+O))                                                              PGM10200
      TTS=SQRT(W*P*D**2/(4.*SIG))                                       PGM10201
      WTS=RHOS*PI*FLOAT(NU)*TTS*(D**2-AN*DO**2)/2.                      PGM10202
      ALI=AL+2.*TTS                                                     PGM10203
      WGHT=(DO**2-D1**2)*PI/4.*ALI*FLOAT(N*NU)*RHOS                     PGM10204
      IF((K.EQ.5).OR.(K.EQ.6).OR.(K.EQ.11).OR.(K.EQ.12))D=SQRT(4.*AT/PI)PGM10205
      WSHELL=RHOS*PI*ALI*D*TSH*FLOAT(NU)                                PGM10206
      TEB=(PD*D)/(4.*SIG)                                               PGM10207
      IF(TEB*12..LT..25) TEB=.25/12.                                    PGM10208
      WEB=(RHOS*PI*((D**2)*TEB*(1.+2.*TEB/D))/2.)*FLOAT(NU)             PGM10209
      ALOA=ALI+D+2.*TEB                                                 PGM10210
      IF((K.EQ.5).OR.(K.EQ.12)) ALOA=ALI+2.*TEB                         PGM10211
      TT=(DO-D1)*6.                                                     PGM10212
       TSH=TSH*12.                                                      PGM10213
      TTS=TTS*12.                                                       PGM10214
      TEB=TEB*12.                                                       PGM10215
      SWGHT=WGHT+WSHELL+WTS+WEB                                         PGM10216
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      TWGHT=SWGHT/2240.                                                 PGM10217
      DODI=DO/D1                                                        PGM10218
      WRITE(6,203) NU,N,A,AL,RE1,RE2,D,VOL,EFF,HEAT                     PGM10219
  203 FORMAT('0',//,T5,' NUMBER OF UNITS = ',I5,//,T5,' NO. TUBES/UNIT = PGM10220
     1',I10,//,T5,' H.T. AREA/UNIT =',F10.2,//,T5,' LENGTH =',F10.2,//, PGM10221
     2T5,' TUBE NRE =',F10.0,//,T5,' SHELL NRE =',F10.0,//,T5,' SHELL DI PGM10222
     3AMETER =',F10.3,//,T5,' VOLUME =',F7.2,//,                        PGM10223
     4     T5,' EFFECTIVENESS =',F6.3,//,T5,' HEAT LOAD (MW) =',F6.2,//) PGM10224
      WRITE(6,204) U1,DTLM,V1,M1,V2,M2                                  PGM10225
  204 FORMAT(' ',T5,' OVERALL U1 =',F10.1,//,T5,' DEL T(LM) =',F7.2//,T5 PGM10226
     1,' TUBE VELOCITY =',F10.2,//,T5,' TUBE MACH NO. =',F10.4,//,T5,' S PGM10227
     2HELL VELOCITY =',F10.2,//,T5,' SHELL MACH NO. =',F10.4)           PGM10228
      WRITE(6,206) PD,F,SIG,D1IN,DOIN,DODI                              PGM10229
  206 FORMAT('0',T20,' HEAT EXCHANGER DESIGN',/,T5,' DESIGN PRESSURE =', PGM10230
     1F8.1,5X,' SAFETY FACTOR =',F4.1,5X,' YIELD STRESS =',F8.0,/,T5,' T PGM10231
     2UBE ID. =',F6.3,' IN.',5X,' TUBE OD. =',F6.3,' IN.',5X,' DO/DI =', PGM10232
     3F7.4)                                                             PGM10233
      WRITE(6,205) WGHT,TT,WSHELL,TSH,WTS,TTS,WEB,TEB,SWGHT,TWGHT,ALOA  PGM10234
  205 FORMAT('0',T5,' CORE',15X,F10.0,10X,F10.4,/,T5,' SHELL',14X,F10.0, PGM10235
     110X,F10.4,/,T5,' TUBE SHEETS',8X,F10.0,10X,F10.4,/,T5,' END CLOSUR PGM10236
     2ES',7X,F10.0,10X,F10.4,//,T5,' TOTAL WEIGHT',7X,F10.0,' (LBS)',4X, PGM10237
     3F10.2,' (TONS)',10X,' TOTAL LENGTH (FT) =',F7.2)                  PGM10238
      GO TO (70,71), KFC                                                PGM10239
   70 DPC=DP1                                                           PGM10240
      DPH=DP2                                                           PGM10241
      GO TO 72                                                          PGM10242
   71 DPC=DP2                                                           PGM10243
      DPH=DP1                                                           PGM10244
   72 WRITE(6,162) TCO,DPH,DPC                                          PGM10245
  162 FORMAT('0',T5,' COOLANT DISCH. TEMP. (R) =',F6.1,10X,' PRESSURE DR PGM10246
     1OP (H) =',F6.3,10X,' PRESSURE DROP (C) =',F6.3)                   PGM10247
      IF((K.EQ.7).OR.(K.EQ.10)) GO TO 150                               PGM10248
      RHOM=RHOS                                                         PGM10249
      GO TO 901                                                         PGM10250
  150 GO TO (151,152), KFC                                              PGM10251
  151 WP=(PI*(D1**2)/4.)*V1*DPC*144.*FLOAT(N*NU)/550.                   PGM10252
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      GO TO 160                                                         PGM10253
  152 WP=(PI*(DO*D2)/4.)*V2*DPC*144.*FLOAT(N*NU)/550.                   PGM10254
  160 WRITE(6,161) WH,WC,WP                                             PGM10255
  161 FORMAT('0',T5,' CO2 FLOW RATE =',F7.1,10X,' WATER FLOW RATE =',F7.PGM10256
     11,10X,' TOTAL COOLER PUMPING POWER (HP) =',F10.0)                 PGM10257
      IF(K.EQ.3)  GO TO 900                                             PGM10258
      RHOM=RHOS                                                         PGM10259
      GO TO 901                                                         PGM10260
  900 RHOM=RHOCN                                                        PGM10261
  901 G2=G1/G1G2                                                        PGM10262
      DPTS=SQRT((2.*W1U)/(PI*G1))                                       PGM10263
      TPTS=(PD*DPTS)/(2.*SIG)                                           PGM10264
      IF(TPTS*12. .LT. .5) TPTS=.5/12.                                  PGM10265
      WPTS=PI*DPTS*TPTS*RHOM                                            PGM10266
      DPSS=SQRT((2.*W2U)/(PI*G2))                                       PGM10267
      TPSS=(PD*DPSS)/(2.*SIG)                                           PGM10268
      IF(TPSS*12. .LT. .5) TPSS=.5/12.                                  PGM10269
      WPSS=PI*DPSS*TPSS*RHOM                                            PGM10270
      F1=ALI*RHO1*AN*FLOAT(NU)                                          PGM10271
      WATT=(F1*PI*D1**2)/4.                                             PGM10272
      WATH=(FLOAT(NU)*PI*RHO1*D**3)/3.                                  PGM10273
      WIPTS=(PI*RHO1*DPTS**2)/4.                                        PGM10274
      F2=(RHO2/RHO1)*F1                                                 PGM10275
      WATSH=(F2*PI*Q*DO**2)/4.                                          PGM10276
      WIPSS=(PI*RHO2*DPSS**2)/4.                                        PGM10277
      TPTSIN=TPTS*12.                                                   PGM10278
      TPSSIN=TPSS*12.                                                   PGM10279
      WRITE(6,600) DPTS,TPTSIN,WPTS,WIPTS,DPSS,TPSSIN,WPSS,WIPSS        PGM10280
  600 FORMAT(' ',T20,' PIPING REQUIREMENTS',/,T20,' DIA (FT)',T33,'T (INPGM10281
     1)',T44,'PIPE (LBS/FT)',10X,'FLUID (LBS/FT)',/,T5,'TUBE SIDE',F14.3PGM10282
     2,F11.3,F17.1,F24.1,/,T5,' SHELL SIDE',F13.3,F11.3,F17.1,F24.1)    PGM10283
      WRITE(6,601) WATT,WATSH,WATH                                      PGM10284
  601 FORMAT('0',T21,'FLUID WEIGHTS'//,T5,' WEIGHT IN TUBES',F11.2,' (LBPGM10285
     1S)',/,T5,' WEIGHT IN SHELL',F11.2,' (LBS)',/,T5,' WEIGHT IN HEADERPGM10286
     2',F10.2,' (LBS)')                                                 PGM10287
      WFINHX=WATT+WATSH+WATH                                            PGM10288
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      WEIGHT=SWGHT+WFINHX                                                PGM10289
      TWGHT=WEIGHT/2240.                                                 PGM10290
      WRITE(6,602) WFINHX,WEIGHT,TWGHT                                   PGM10291
  602 FORMAT('0',T20,'TOTAL SYSTEM WEIGHT',/,T5,' FLUID IN HX',F10.2,' ( PGM10292
     1LBS)',/,T5,' EQUIPMENT',F12.2,' (LBS)',/,T5,' TOTAL     ',F12.2,' ( PGM10293
     3TONS)')                                                            PGM10294
   50 CONTINUE                                                           PGM10295
      STOP                                                               PGM10296
      END                                                                PGM10297
      SUBROUTINE HELIUM(T,P,H,RHO,CV,CP,VS,CK,VI,S,PR)                   PGM10298
      DATA A,B,R,D / .06310, .0005342,  2.68111, 1.4234E-07 /            PGM10299
      DATA STO,TO,CPO,HO,PO / 7.281, 450., 1.2413, 5.4, 14.696 /         PGM10300
      DATA SFT,CF,GO,C1 / 144., .18508, -32.1667, 2.5182E-05 /           PGM10301
      KKK=1                                                              PGM10302
      IF(T.LT.450.) GO TO 32                                             PGM10303
      IF(T.GT.3000.) GO TO 32                                            PGM10304
      IF(P.LT. .1) GO TO 31                                              PGM10305
      IF(P.GT.3000.) GO TO 32                                            PGM10306
      GO TO 33                                                           PGM10307
   31 P=.1                                                               PGM10308
   32 IF(KKK.GT.20) GO TO 33                                             PGM10309
      KKK=KKK+1                                                          PGM10310
      WRITE(6,101) T,P                                                   PGM10311
  101 FORMAT(26H0IND. VAR. OUT OF RANGE T=,E12.4,3H P=,E12.4)            PGM10312
   33 SRT=SQRT(T)                                                        PGM10313
      RTP=R*T/P                                                          PGM10314
      BT=B*SRT                                                           PGM10315
      BOT=B/SRT/2.                                                       PGM10316
      V=RTP+A-BT                                                         PGM10317
      CP=CPO-(.5*BOT*P*CF)                                               PGM10318
      DVDP=-RTP/P                                                        PGM10319
      CV=CP+T*(((R/P-BOT)**2.)*CF)/DVDP                                  PGM10320
      VS=V*SQRT(GO*CP/(CV*DVDP/SFT))                                     PGM10321
      VI=D*T**.719215/(1.-5288./T**2)                                    PGM10322
      CK=6696.*VI+.00336/V                                               PGM10323
      S=STO+CPO*ALOG(T/TO)-(R*ALOG(P/PO)-BOT*(P-PO)-.5*P*(B/SRT-C1))*CF PGM10324
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      H=CPO*T+HO+P*CP*(A-.5*BT)                                    PGM10325
      CK=CK/3600.                                                  PGM10326
      PR=CP*VI/CK                                                  PGM10327
      RHO=1./V                                                     PGM10328
      RETURN                                                       PGM10329
      END                                                          PGM10330
      SUBROUTINE WATER(TB,RHO,CP,VI,CK,PR)                         PGM10331
      COMMON T(20),RHOW(20),CPW(20),VISW(20),TKW(20)               PGM10332
      FIT(A,B,C)=A+(B-A)*C                                         PGM10333
      DO 1 I=1,20                                                  PGM10334
      IF(TB-T(I)) 2,2,1                                            PGM10335
    1 CONTINUE                                                     PGM10336
    2 X=(TB-T(I-1))/(T(I)-T(I-1))                                  PGM10337
      CP=FIT(CPW(I-1),CPW(I),X)                                    PGM10338
      RHO=FIT(RHOW(I-1),RHOW(I),X)                                 PGM10339
      VI=FIT(VISW(I-1),VISW(I),X)                                  PGM10340
      CK=FIT(TKW(I-1),TKW(I),X)                                    PGM10341
      PR=CP*VI/CK                                                  PGM10342
      RETURN                                                       PGM10343
      END                                                          PGM10344
      SUBROUTINE CO2P1(RHO,CP,CK,VI,PR,VS)                         PGM10345
      RHO= 18.13                                                   PGM10346
      CP = .3199                                                   PGM10347
      CK = .0286/3600.0                                            PGM10348
      VI = .08175/3600.0                                           PGM10349
      PR = .9144                                                   PGM10350
      VS = 1285.73                                                 PGM10351
      RETURN                                                       PGM10352
      END                                                          PGM10353
      SUBROUTINE CO2P2(RHO,CP,CK,VI,PR,VS)                         PGM10354
      RHO= 6.82                                                    PGM10355
      CP = .28                                                     PGM10356
      CK = .02527/3600.0                                           PGM10357
      VI = .06988/3600.0                                           PGM10358
      PR = .7743                                                   PGM10359
      VS = 1239.3                                                  PGM10360
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RETURN                                                  PGM10361
END                                                     PGM10362
SUBROUTINE AIR1(RHO,CP,CK,VI,PR,VS)                     PGM10363
RHO= .04159                                             PGM10364
CP = .2513                                              PGM10365
CK = .0272/3600.0                                       PGM10366
VI = .063/3600.0                                        PGM10367
PR = .582                                               PGM10368
VS = 1582.24                                            PGM10369
RETURN                                                  PGM10370
END                                                     PGM10371
SUBROUTINE AIR2(RHO,CP,CK,VI,PR,VS)                     PGM10372
RHO= .03098                                             PGM10373
CP = .2583                                              PGM10374
CK = .0323/3600.0                                       PGM10375
VI = .08329/3600.0                                      PGM10376
PR = .666                                               PGM10377
VS = 1750.62                                            PGM10378
RETURN                                                  PGM10379
END                                                     PGM10380
SUBROUTINE CO2H1(RHO,CP,CK,VI,PR,VS)                    PGM10381
RHO= 10.67                                              PGM10382
CP = .3042                                              PGM10383
CK = .0385/3600.0                                       PGM10384
VI = .09419/3600.0                                      PGM10385
PR = .7442                                              PGM10386
VS = 1597.0                                             PGM10387
RETURN                                                  PGM10388
END                                                     PGM10389
SUBROUTINE AIRH2(RHO,CP,CK,VI,PR,VS)                    PGM10390
RHO= .012316                                            PGM10391
CP = .295                                               PGM10392
CK = .075/3600.0                                        PGM10393
VI = .13788/3600.0                                      PGM10394
PR = .5423                                              PGM10395
VS = 2755.0                                             PGM10396
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      RETURN                                                              PGM10397
      END                                                                 PGM10398
      SUBROUTINE CO2C(RHC,CP,CK,VI,PR,VS)                                 PGM10399
      RHO= 33.52                                                          PGM10400
      CP = .922                                                           PGM10401
      CK = .03765/3600.0                                                  PGM10402
      VI = .12698/3600.0                                                  PGM10403
      PR = 3.11                                                           PGM10404
      VS = 1154.22                                                        PGM10405
      RETURN                                                              PGM10406
      END                                                                 PGM10407
      SUBROUTINE SWATER(TB,RHO,CP,VI,CK,PR)                               PGM10408
      COMMON T(20),RHOW(20),CPW(20),VISW(20),TKW(20)                      PGM10409
      FIT(A,B,C)=A+(B-A)*C                                                PGM10410
      DO 1 I=1,20                                                         PGM10411
      IF(TB-T(I)) 2,2,1                                                   PGM10412
    1 CONTINUE                                                            PGM10413
    2 X=(TB-T(I-1))/(T(I)-T(I-1))                                         PGM10414
      CP=FIT(CPW(I-1),CPW(I),X)                                           PGM10415
      RHO=FIT(RHOW(I-1),RHOW(I),X)*(1.028307-(2.46E-05*(TB-460.)))        PGM10416
      VI=FIT(VISW(I-1),VISW(I),X)*(0.8775524*(TB-460.)**(0.0424963))      PGM10417
      CK=FIT(TKW(I-1),TKW(I),X)                                           PGM10418
      PR=CP*VI/CK                                                         PGM10419
      RETURN                                                              PGM10420
      END                                                                 PGM10421
      SUBROUTINE RCP11(RHO,CP,CK,VI,PR,VS)                                PGM10422
      RHO=38.55                                                           PGM10423
      CP =.513                                                            PGM10424
      CK =.0375/3600.                                                     PGM10425
      VI =.12388/3600.                                                    PGM10426
      VS =1280.                                                           PGM10427
      PR =1.695                                                           PGM10428
      RETURN                                                              PGM10429
      END                                                                 PGM10430
      SUBROUTINE RCP12(RHC,CP,CK,VI,PR,VS)                                PGM10431
      RHO=10.12                                                           PGM10432
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```
      CP =.33                                                           PGM10433
      CK =.01706/3600.                                                  PGM10434
      VI =.05381/3600.                                                  PGM10435
      PR =1.04                                                          PGM10436
      VS =909.                                                          PGM10437
      RETURN                                                            PGM10438
      END                                                               PGM10439
      SUBROUTINE PCP21(RHO,CP,CK,VI,PR,VS)                              PGM10440
      RHO=14.19                                                         PGM10441
      CP =.303                                                          PGM10442
      CK =.02932/3600.                                                  PGM10443
      VI =.0902/3600.                                                   PGM10444
      VS =1336.                                                         PGM10445
      PR =.828                                                          PGM10446
      RETURN                                                            PGM10447
      END                                                               PGM10448
      SUBROUTINE PCP22(RHO,CP,CK,VI,PR,VS)                              PGM10449
      RHO=4.93                                                          PGM10450
      CP =.2775                                                         PGM10451
      CK =.02645/3600.                                                  PGM10452
      VI =.07182/3600.                                                  PGM10453
      VS =1278.                                                         PGM10454
      PR =.753                                                          PGM10455
      RETURN                                                            PGM10456
      END                                                               PGM10457
      SUBROUTINE COCL1(RHO,CP,CK,VI,PR,VS)                              PGM10458
      RHO=24.08                                                         PGM10459
      CP =1.7733                                                        PGM10460
      CK =.0224/3600.                                                   PGM10461
      VI =.0729/3600.                                                   PGM10462
      VS =699.                                                          PGM10463
      PR =5.77                                                          PGM10464
      RETURN                                                            PGM10465
      END                                                               PGM10466
      SUBROUTINE COMBS1(RHO,CP,CK,VI,PR,VS)                             PGM10467
      RHO=9.17                                                          PGM10468
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```
      CP =.303                                                          PGM10469
      CK =.0388/3600.                                                   PGM10470
      VI =.09398/3600.                                                  PGM10471
      VS =1595.                                                         PGM10472
      PR =.73                                                           PGM10473
      RETURN                                                            PGM10474
      END                                                               PGM10475
      SUBROUTINE COMBS2(RHO,CP,CK,VI,PR,VS)                             PGM10476
      RHO=.012316                                                       PGM10477
      CP =.295                                                          PGM10478
      CK =.075/3600.                                                    PGM10479
      VI =.13788/3600.                                                  PGM10480
      PR =.5423                                                         PGM10481
      VS =2755.                                                         PGM10482
      RETURN                                                            PGM10483
      END                                                               PGM10484
      SUBROUTINE PHEAT1(RHO,CP,CK,VI,PR,VS)                             PGM10485
      RHO=.031                                                          PGM10486
      CP =.255                                                          PGM10487
      CK =.03/3600.                                                     PGM10488
      VI =.07848/3600.                                                  PGM10489
      PR =.66                                                           PGM10490
      VS =1679.                                                         PGM10491
      RETURN                                                            PGM10492
      END                                                               PGM10493
      SUBROUTINE PHEAT2(RHO,CP,CK,VI,PR,VS)                             PGM10494
      RHO=.04                                                           PGM10495
      CP =.25                                                           PGM10496
      CK =.027/3600.                                                    PGM10497
      VI =.063/3600.                                                    PGM10498
      PR =.58                                                           PGM10499
      VS=1580.                                                          PGM10500
      RETURN                                                            PGM10501
      END                                                               PGM10502
$ENTRY                                                                  PGM10503
     510.      62.4       1.0015      8.763E-04       9.42E-05          PGM10504
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528.	62.32	0.999	6.733E-04	9.68E-05	PGM10505
546.	62.16	0.998	5.365E-04	9.92E-05	PGM10506
564.	61.94	0.998	4.394E-04	1.01E-04	PGM10507
582.	61.68	0.998	3.681E-04	1.03E-04	PGM10508
600.	61.38	0.999	3.140E-04	1.05E-04	PGM10509
618.	61.04	1.001	2.720E-04	1.06E-04	PGM10510
636.	60.67	1.002	2.388E-04	1.08E-04	PGM10511
654.	60.27	1.005	2.121E-04	1.08E-04	PGM10512
672.	59.83	1.007	1.902E-04	1.09E-04	PGM10513
690.	59.37	1.010	1.712E-04	1.10E-04	PGM10514
708.	58.88	1.013	1.552E-04	1.10E-04	PGM10515
726.	58.36	1.018	1.417E-04	1.10E-04	PGM10516
744.	57.82	1.023	1.304E-04	1.10E-04	PGM10517
762.	57.24	1.028	1.208E-04	1.10E-04	PGM10518
780.	56.66	1.035	1.127E-04	1.10E-04	PGM10519
798.	56.02	1.043	1.058E-04	1.09E-04	PGM10520
816.	55.37	1.051	9.979E-05	1.09E-04	PGM10521
834.	54.69	1.062	9.455E-05	1.08E-04	PGM10522
852.	53.98	1.073	8.998E-05	1.07E-04	PGM10523

APPENDIX III

SUMMARY OF SHIPS

LBP	410.00	DISP FLD	3634.85	FLD DENS	19.91
BEAM	40.96	DISP LSP	2432.21	LSP DENS	13.32
DRAFT	15.93	VR LOADS	959.41	WPAY/FLD	0.12
D 0	42.37	WT MARG	243.22	WPER/FLD	0.04
D 10	32.00	WTGRP 1	1113.81	WOPS/FLD	0.41
D 20	32.41	WTGRP 2	273.98	VPAY/VOL	0.18
D AVG	33.80	WTGRP 3	149.14	VPER/VOL	0.22
LEN R DK	0.00	WTGRP 4	220.29	VOPS/VOL	0.60
CP	0.60	WTGRP 5	315.27	WTG2/SHP	15.34
CX	0.78	WTGRP 6	224.15	VMB/SHP	2.33
VCG FLD	16.28	WTGRP 7	135.57	WT3/KWIN	83.52
VCG/DAVG	0.48	VCI TOT	409011.60	WTG1/VOL	6.10
L/B	10.01	VOL HULL	345737.90	WTG5/VOL	1.73
B/H	2.57	VOL SSTR	63273.77	VHAB/MAN	425.59
EXCES KG	0.00	CRUISEKW	2251.65	WHAB/MAN	728.05
RANGE	4500.00	BATTLEKW	1877.82	MEN/DISP	0.05
SUS SHP	40000.00	24 HR KW	1347.43	KWIN/FLD	1.10
END SHP	7410.24	NU LOWSD	0.00	SHP/DISP	11.00
VSUS	30.45	NU MEDSD	4.00		
VEND	20.00	NU HI SD	0.00		
AVSEASPD	27.70	NU GT GN	0.00		
NU ACCOM	190.00	NU ST GN	0.00		
KW INST	4000.00	KW/DIESL	1000.00		
KW SPSER	4000.00	KW/GAS T	0.00		
KW EMERG	0.00	KW/STM G	0.00		

PROPULSION PLANT: GAS TURBINE (BASE CASE)

FUEL REQUIRED: 663.6 TONS

LBP	410.00	DISP FLD	3368.98	FLD DENS	18.63
BEAM	41.02	DISP LSP	2345.79	LSP DENS	12.97
DRAFT	14.73	VP LOADS	788.62	WPAY/FLD	0.13
D 0	39.97	WT MARG	234.58	WPER/FLD	0.04
D 10	32.00	WTGRP 1	1050.51	WOPS/FLD	0.39
D 20	32.41	WTGRP 2	293.85	VPAY/VOL	0.19
D AVG	33.40	WTGRP 3	120.97	VPER/VOL	0.23
LEN R DK	0.00	WTGRP 4	219.16	VOPS/VOL	0.59
CP	0.60	WTGRP 5	303.89	WTG2/SHP	16.46
CX	0.78	WTGRP 6	221.83	VMB/SHP	2.64
VCG FLD	16.42	WTGRP 7	135.57	WT3/KWIN	90.32
VCG/DAVG	0.49	VOL TOT	404994.90	WTG1/VOL	5.81
L/B	10.00	VOL HULL	349858.10	WTG5/VOL	1.68
B/H	2.78	VOL SSTR	55136.79	VHAB/MAN	425.59
EXCES KG	0.00	CRUISEKW	2169.55	WHAB/MAN	728.21
RANGE	4500.00	BATTLEKW	1820.76	MEN/DISP	0.06
SUS SHP	40000.00	24 HR KW	1277.31	KWIN/FLD	0.89
END SHP	7080.69	NU LOWSD	0.00	SHP/DISP	11.87
VSUS	31.28	NU MEDSD	4.00		
VEND	20.00	NU HI SD	0.00		
AVSEASPD	28.21	NU GT GN	0.00		
NU ACCOM	190.00	NU ST GN	0.00		
KW INST	3000.00	KW/DIESL	750.00		
KW SPSER	3000.00	KW/GAS T	0.00		
KW EMERG	0.00	KW/STM G	0.00		

PROPULSION PLANT: FEHER BASIC ENGINE

FUEL REQUIRED: 496.6 Tons

LBP	410.00	DISP FLD	3470.79	FLD DENS	19.33
BEAM	40.90	DISP LSP	2373.07	LSP DENS	13.22
DRAFT	15.29	VR LOADS	860.41	WPAY/FLD	0.13
D 0	41.09	WT MARG	237.31	WPER/FLD	0.04
D 10	32.00	WTGRP 1	1073.69	WOPS/FLD	0.40
D 20	32.41	WTGRP 2	295.00	VPAY/VOL	0.18
D AVG	33.58	WTGRP 3	120.39	VPER/VOL	0.23
LEN R DK	0.00	WTGRP 4	219.42	VOPS/VOL	0.59
CP	0.60	WTGRP 5	307.36	WTG2/SHP	16.52
CX	0.78	WTGRP 6	221.64	VMB/SHP	2.62
VCG FLD	16.34	WTGRP 7	135.57	WT3/KWIN	89.89
VCG/DAVG	0.49	VOL TOT	402198.70	WTG1/VOL	5.98
L/B	10.03	VOL HULL	347062.00	WTG5/VOL	1.71
B/H	2.67	VOL SSTR	55136.79	VHAB/MAN	425.59
EXCES KG	0.00	CRUISEKW	2205.38	WHAB/MAN	728.14
RANGE	5000.00	BATTLEKW	1845.62	MEN/DISP	0.05
SUS SHP	40000.00	24 HR KW	1307.83	KWIN/FLD	0.86
END SHP	7212.93	NU LOWSD	0.00	SHP/DISP	11.52
VSUS	30.91	NU MEDSD	4.00		
VEND	20.00	NU HI SD	0.00		
AVSEASPD	27.99	NU GT GN	0.00		
NU ACCOM	190.00	NU ST GN	0.00		
KW INST	3000.00	KW/DIESL	750.00		
KW SPSER	3000.00	KW/GAS T	0.00		
KW EMERG	0.00	KW/STM G	0.00		

PROPULSION PLANT: FEHER BASIC ENGINE

FUEL REQUIRED: 557.3 TONS

LBP	410.00	DISP FLD	3574.92	FLD DENS	19.94
BEAM	40.86	DISP LSP	2401.30	LSP DENS	13.39
DRAFT	15.77	VR LOADS	933.49	WPAY/FLD	0.12
D 0	42.05	WT MARG	240.13	WPER/FLD	0.04
D 10	32.00	WTGRP 1	1096.36	WOPS/FLD	0.41
D 20	32.41	WTGRP 2	296.18	VPAY/VOL	0.18
D AVG	33.74	WTGRP 3	120.27	VPER/VOL	0.23
LEN R DK	0.00	WTGRP 4	219.75	VOPS/VOL	0.59
CP	0.60	WTGRP 5	311.18	WTG2/SHP	16.59
CX	0.78	WTGRP 6	222.00	VMB/SHP	2.61
VCG FLD	16.26	WTGRP 7	135.57	WT3/KWIN	89.80
VCG/DAVG	0.48	VOL TOT	401614.00	WTG1/VOL	6.11
L/B	10.03	VOL HULL	345337.80	WTG5/VOL	1.74
B/H	2.59	VOL SSTR	56276.19	VHAB/MAN	425.59
EXCES KG	0.00	CRUISEKW	2237.60	WHAB/MAN	728.08
RANGE	5500.00	BATTLEKW	1868.00	MEN/DISP	0.05
SUS SHP	40000.00	24 HR KW	1335.36	KWIN/FLD	0.84
END SHP	7344.35	NU LOWSD	0.00	SHP/DISP	11.19
VSUS	30.59	NU MEDSD	4.00		
VEND	20.00	NU HI SD	0.00		
AVSEASPD	27.79	NU GT GN	0.00		
NU ACCOM	190.00	NU ST GN	0.00		
KW INST	3000.00	KW/DIESL	750.00		
KW SPSER	3000.00	KW/GAS T	0.00		
KW EMERG	0.00	KW/STM G	0.00		

PROPULSION PLANT: FEHER BASIC ENGINE

FUEL REQUIRED: 619.2 TONS

LBP	410.00	DISP FLD	3743.65	FLD DENS	20.67
BEAM	40.92	DISP LSP	2481.80	LSP DENS	13.70
DRAFT	16.46	VR LOADS	1013.66	WPAY/FLD	0.12
D 0	43.44	WT MARG	248.18	WPER/FLD	0.04
D 10	32.00	WTGRP 1	1136.39	WOPS/FLD	0.42
D 20	32.41	WTGRP 2	299.37	VPAY/VOL	0.18
D AVG	33.97	WTGRP 3	148.45	VPER/VOL	0.22
LEN 2 DK	0.00	WTGRP 4	220.52	VOPS/VOL	0.59
CP	0.60	WTGRP 5	317.60	WTG2/SHP	16.76
CX	0.78	WTGRP 6	223.90	VMB/SHP	2.59
VCG FLD	16.24	WTGRP 7	135.57	WT3/KWIN	83.13
VCG/DAVG	0.48	VOL TOT	405668.40	WTG1/VOL	6.27
L/B	10.02	VOL HULL	343965.50	WTG5/VOL	1.75
B/H	2.49	VOL SSTR	61702.94	VHAB/MAN	425.59
EXCES KG	0.00	CRUISEKW	2287.68	WHAB/MAN	727.99
RANGE	6000.00	BATTLEKW	1902.90	MEN/DISP	0.05
SUS SHP	40000.00	24 HR KW	1378.12	KWIN/FLD	1.07
END SHP	7566.23	NU LOWSD	0.00	SHP/DISP	10.68
VSUS	30.15	NU MEDSD	4.00		
VEND	20.00	NU HI SD	0.00		
AVSEASPD	27.52	NU GT GN	0.00		
NU ACCOM	190.00	NU ST GN	0.00		
KW INST	4000.00	KW/DIESL	1000.00		
KW SPSER	4000.00	KW/GAS T	0.00		
KW EMERG	0.00	KW/STM G	0.00		

PROPULSION PLANT: FEHER BASIC ENGINE

FUEL REQUIRED: 686.6 TONS

LBP	410.00	DISP FLD	3515.61	FLD DENS	19.47
BEAM	41.19	DISP LSP	2470.03	LSP DENS	13.68
DRAFT	15.36	VR LOADS	798.58	WPAY/FLD	0.12
D 0	41.23	WT MARG	247.00	WPER/FLD	0.04
D 10	32.00	WTGRP 1	1084.12	WOPS/FLD	0.40
D 20	32.41	WTGRP 2	379.76	VPAY/VOL	0.19
D AVG	33.61	WTGRP 3	120.86	VPER/VOL	0.23
LEN R DK	0.00	WTGRP 4	219.68	VOPS/VOL	0.59
CP	0.60	WTGRP 5	307.42	WTG2/SHP	21.27
CX	0.78	WTGRP 6	222.62	VMB/SHP	2.63
VCG FLD	16.42	WTGRP 7	135.57	WT3/KWIN	90.24
VCG/DAVG	0.49	VOL TOT	404494.50	WTG1/VOL	6.00
L/B	9.95	VOL HULL	349357.70	WTG5/VOL	1.70
B/H	2.68	VOL SSTR	55136.79	VHAB/MAN	425.59
EXCES KG	0.00	CRUISEKW	2217.91	WHAB/MAN	728.11
RANGE	4500.00	BATTLEKW	1854.31	MEN/DISP	0.05
SUS SHP	40000.00	24 HR KW	1318.60	KWIN/FLD	0.85
END SHP	7283.54	NU LCWSD	0.00	SHP/DISP	11.38
VSUS	30.77	NU MEDSD	4.00		
VEND	20.00	NU HI SD	0.00		
AVSEASPD	27.88	NU GT GN	0.00		
NU ACCOM	190.00	NU ST GN	0.00		
KW INST	3000.00	KW/DIESL	750.00		
KW SPSER	3000.00	KW/GAS T	0.00		
KW EMERG	0.00	KW/STM G	0.00		

PROPULSION PLANT: FEHER BASIC ENGINE (MODIFIED)

FUEL REQUIRED: 504.3 TONS

LBP	410.00	DISP FLD	3663.35	FLD DENS	20.41
BEAM	41.13	DISP LSP	2535.46	LSP DENS	14.13
DRAFT	16.04	VR LOADS	874.35	WPAY/FLD	0.12
D 0	42.60	WT MARG	253.55	WPER/FLD	0.04
D 10	32.00	WTGRP 1	1114.72	WOPS/FLD	0.42
D 20	32.41	WTGRP 2	382.89	VPAY/VOL	0.18
D AVG	33.83	WTGRP 3	147.70	VPER/VOL	0.23
LEN R DK	0.00	WTGRP 4	220.06	VOPS/VOL	0.59
CP	0.60	WTGRP 5	311.78	WTG2/SHP	21.44
CX	0.78	WTGRP 6	222.73	VMB/SHP	2.61
VCG FLD	16.35	WTGRP 7	135.57	WT3/KWIN	82.71
VCG/DAVG	0.48	VOL TOT	402015.30	WTG1/VOL	6.21
L/B	9.97	VOL HULL	346878.50	WTG5/VOL	1.74
B/H	2.56	VOL SSTR	55136.79	VHAB/MAN	425.59
EXCES KG	0.00	CRUISEKW	2263.87	WHAB/MAN	728.03
$\boxed{\text{RANGE} \quad 5000.00}$		BATTLEKW	1886.16	MEN/DISP	0.05
SUS SHP	40000.00	24 HR KW	1357.80	KWIN/FLD	1.09
END SHP	7473.51	NU LOWSD	0.00	SHP/DISP	10.92
VSUS	30.32	NU MEDSD	4.00		
VEND	20.00	NU HI SD	0.00		
AVSEASPD	27.61	NU GT GN	0.00		
NU ACCOM	190.00	NU ST GN	0.00		
KW INST	4000.00	KW/DIESL	1000.00		
KW SPSER	4000.00	KW/GAS T	0.00		
KW EMERG	0.00	KW/STM G	0.00		

PROPULSION PLANT: FEHER BASIC ENGINE (MODIFIED)

FUEL REQUIRED: 568.3 TONS

LBP	410.00	DISP FLD	3769.80	FLD DENS	20.93
BEAM	41.08	DISP LSP	2564.96	LSP DENS	14.24
DRAFT	16.47	VP LOADS	948.35	WPAY/FLD	0.12
D 0	43.46	WT MARG	256.50	WPER/FLD	0.04
D 10	32.00	WTGRP 1	1137.32	WOPS/FLD	0.43
D 20	32.41	WTGRP 2	384.07	VPAY/VOL	0.18
D AVG	33.98	WTGRP 3	148.01	VPER/VOL	0.23
LEN R DK	0.00	WTGRP 4	220.47	VOPS/VOL	0.59
CP	0.60	WTGRP 5	315.94	WTG2/SHP	21.51
CX	0.78	WTGRP 6	223.57	VMB/SHP	2.60
VCG FLD	16.29	WTGRP 7	135.57	WT3/KWIN	82.89
VCG/DAVG	0.48	VOL TOT	403534.50	WTG1/VOL	6.31
L/B	9.98	VOL HULL	345281.70	WTG5/VOL	1.75
B/H	2.49	VOL SSTR	58252.75	VHAB/MAN	425.59
EXCES KG	0.00	CRUISEKW	2292.97	WHAB/MAN	727.98
RANGE	5500.00	BATTLEKW	1906.44	MEN/DISP	0.05
SUS SHP	40000.00	24 HR KW	1382.53	KWIN/FLD	1.06
END SHP	7598.51	NU LOWSD	0.00	SHP/DISP	10.61
VSUS	30.10	NU MEDSD	4.00		
VEND	20.00	NU HI SD	0.00		
AVSEASPD	27.49	NU GT GN	0.00		
NU ACCOM	190.00	NU ST GN	0.00		
KW INST	4000.00	KW/DIESL	1000.00		
KW SPSER	4000.00	KW/GAS T	0.00		
KW EMERG	0.00	KW/STM G	0.00		

PROPULSION PLANT: FEHER BASIC ENGINE (MODIFIED)

FUEL REQUIRED: 630.9 TONS

LBP	410.00	DISP FLD	3898.47	FLD DENS	21.42
BEAM	41.23	DISP LSP	2609.21	LSP DENS	14.34
DRAFT	17.02	VR LOADS	1028.34	WPAY/FLD	0.11
D 0	44.57	WT MARG	260.92	WPER/FLD	0.03
D 10	32.27	WTGRP 1	1170.63	WOPS/FLD	0.43
D 20	32.68	WTGRP 2	385.36	VPAY/VOL	0.18
D AVG	34.39	WTGRP 3	148.86	VPER/VOL	0.22
LEN R DK	0.00	WTGRP 4	221.16	VOPS/VOL	0.59
CP	0.60	WTGRP 5	322.00	WTG2/SHP	21.58
CX	0.78	WTGRP 6	225.64	VMB/SHP	2.59
VCG FLD	16.32	WTGRP 7	135.57	WT3/KWIN	83.36
VCG/DAVG	0.47	VOL TOT	407626.20	WTG1/VOL	6.43
L/B	9.94	VOL HULL	348180.00	WTG5/VOL	1.77
B/H	2.42	VOL SSTR	59446.19	VHAB/MAN	425.59
EXCES KG	0.00	CRUISEKW	2336.19	WHAB/MAN	727.91
RANGE	6000.00	BATTLEKW	1936.81	MEN/DISP	0.05
SUS SHP	40000.00	24 HR KW	1419.49	KWIN/FLD	1.03
END SHP	7801.98	NU LCWSD	0.00	SHP/DISP	10.26
VSUS	29.78	NU MEDSD	4.00		
VEND	20.00	NU HI SD	0.00		
AVSEASPD	27.30	NU GT GN	0.00		
NU ACCOM	190.00	NU ST GN	0.00		
KW INST	4000.00	KW/DIESL	1000.00		
KW SPSFR	4000.00	KW/GAS T	0.00		
KW EMERG	0.00	KW/STM G	0.00		

PROPULSION PLANT: FEHER BASIC ENGINE (MODIFIED)

FUEL REQUIRED: 698.5 TONS

LBP	410.00	DISP FLD	3523.57	FLD DENS	19.23
BEAM	41.27	DISP LSP	2495.59	LSP DENS	13.62
DRAFT	15.35	VR LOADS	778.42	WPAY/FLD	0.12
D C	41.22	WT MARG	249.56	WPER/FLD	0.04
D 10	32.00	WTGRP 1	1091.89	WOPS/FLD	0.40
D 20	32.41	WTGRP 2	393.37	VPAY/VOL	0.18
D AVG	33.60	WTGRP 3	122.09	VPER/VOL	0.22
LEN R DK	0.00	WTGRP 4	220.01	VOPS/VOL	0.60
CP	0.60	WTGRP 5	308.48	WTG2/SHP	22.03
CX	0.78	WTGRP 6	224.18	VMB/SHP	2.97
VCG FLD	16.50	WTGRP 7	135.57	WT3/KWIN	91.16
VCG/DAVG	0.49	VCL TOT	410428.50	WTG1/VOL	5.96
L/B	9.93	VCL HULL	350042.00	WTG5/VOL	1.68
B/H	2.69	VCL SSTR	60386.50	VHAB/MAN	425.59
EXCES KG	0.00	CRUISEKW	2219.55	WHAB/MAN	728.11
RANGE	4500.00	BATTLEKW	1855.53	MEN/DISP	0.05
SUS SHP	40000.00	24 HR KW	1320.07	KWIN/FLD	0.85
END SHP	7295.09	NU LOWSD	0.00	SHP/DISP	11.35
VSUS	30.75	NU MEDSD	4.00		
VEND	20.00	NU HI SD	0.00		
AVSEASPD	27.86	NU GT GN	0.00		
NU ACCOM	190.00	NU ST GN	0.00		
KW INST	3000.00	KW/DIESL	750.00		
KW SPSER	3000.00	KW/GAS T	0.00		
KW EMERG	0.00	KW/STM G	0.00		

PROPULSION PLANT: RECOMPRESSION ENGINE

FUEL REQUIRED: 484.0 TONS

LBP	410.00	DISP FLD	3681.47	FLD DENS	19.90
BEAM	41.40	DISP LSP	2574.30	LSP DENS	13.92
DRAFT	15.99	VR LOADS	849.74	WPAY/FLD	0.12
D 0	42.51	WT MARG	257.43	WPER/FLD	0.04
D 10	32.00	WTGRP 1	1130.66	WOPS/FLD	0.41
D 20	32.41	WTGRP 2	396.41	VPAY/VOL	0.18
D AVG	33.82	WTGRP 3	150.25	VPER/VOL	0.22
LEN R DK	0.00	WTGRP 4	220.76	VOPS/VOL	0.60
CP	0.60	WTGRP 5	314.56	WTG2/SHP	22.20
CX	0.78	WTGRP 6	226.07	VMB/SHP	2.96
VCG FLD	16.46	WTGRP 7	135.57	WT3/KWIN	84.14
VCG/DAVG	0.49	VOL TOT	414366.50	WTG1/VOL	6.11
L/B	9.90	VOL HULL	349299.30	WTG5/VOL	1.70
B/H	2.59	VOL SSTR	65067.25	VHAB/MAN	425.59
EXCES KG	0.00	CRUISEKW	2268.27	WHAB/MAN	728.02
RANGE	5000.00	BATTLEKW	1889.39	MEN/DISP	0.05
SUS SHP	40000.00	24 HR KW	1361.72	KWIN/FLD	1.09
END SHP	7507.28	NU LOWSD	0.00	SHP/DISP	10.87
VSUS	30.28	NU MEDSD	4.00		
VEND	20.00	NU HI SD	0.00		
AVSEASPD	27.57	NU GT GN	0.00		
NU ACCOM	190.00	NU ST GN	0.00		
KW INST	4000.00	KW/DIESL	1000.00		
KW SPSER	4000.00	KW/GAS T	0.00		
KW EMERG	0.00	KW/STM G	0.00		

PROPULSION PLANT: RECOMPRESSION ENGINE

FUEL REQUIRED: 534.5 TONS

LBP	410.00	DISP FLD	3793.12	FLD DENS	20.35
BEAM	41.29	DISP LSP	2611.56	LSP DENS	14.01
DRAFT	16.53	VR LOADS	920.40	WPAY/FLD	0.11
D C	43.59	WT MARG	261.16	WPER/FLD	0.04
D 10	32.00	WTGRP 1	1159.42	WOPS/FLD	0.42
D 20	32.41	WTGRP 2	397.53	VPAY/VOL	0.18
D AVG	34.00	WTGRP 3	150.90	VPER/VOL	0.22
LEN R DK	0.00	WTGRP 4	221.31	VOPS/VOL	0.60
CP	0.60	WTGRP 5	319.45	WTG2/SHP	22.26
CX	0.78	WTGRP 6	227.37	VMB/SHP	2.94
VCG FLD	16.44	WTGRP 7	135.57	WT3/KWIN	84.50
VCG/DAVG	0.48	VOL TOT	417512.60	WTG1/VOL	6.22
L/B	9.93	VOL HULL	346850.00	WTG5/VOL	1.71
B/H	2.50	VOL SSTR	70662.69	VHAB/MAN	425.59
EXCES KG	0.00	CRUISEKW	2303.50	WHAB/MAN	727.96
RANGE	5500.00	BATTLEKW	1914.08	MEN/DISP	0.05
SUS SHP	40000.00	24 HR KW	1391.73	KWIN/FLD	1.05
END SHP	7654.78	NU LOWSD	0.00	SHP/DISP	10.55
VSUS	30.02	NU MEDSD	4.00		
VEND	20.00	NU HI SD	0.00		
AVSEASPD	27.43	NU GT GN	0.00		
NU ACCOM	190.00	NU ST GN	0.00		
KW INST	4000.00	KW/DIESL	1000.00		
KW SPSER	4000.00	KW/GAS T	0.00		
KW EMERG	0.00	KW/STM G	0.00		

PROPULSION PLANT: RECOMPRESSION ENGINE

FUEL REQUIRED: 602.4 TONS

LBP	410.00	DISP FLD	3908.52	FLD DENS	20.77
BEAM	41.59	DISP LSP	2649.84	LSP DENS	14.08
DRAFT	16.91	VR LOADS	993.70	WPAY/FLD	0.11
D 0	44.36	WT MARG	264.98	WPER/FLD	0.03
D 10	32.06	WTGRP 1	1187.87	WOPS/FLD	0.43
D 20	32.47	WTGRP 2	398.69	VPAY/VOL	0.18
D AVG	34.17	WTGRP 3	151.75	VPER/VOL	0.22
LEN R DK	0.00	WTGRP 4	221.93	VOPS/VOL	0.61
CP	0.60	WTGRP 5	324.78	WTG2/SHP	22.33
CX	0.78	WTGRP 6	229.24	VMB/SHP	2.95
VCG FLD	16.39	WTGRP 7	135.57	WT3/KWIN	84.98
VCG/DAVG	0.48	VOL TOT	421596.70	WTG1/VOL	6.31
L/B	9.86	VOL HULL	349058.40	WTG5/VOL	1.73
B/H	2.46	VOL SSTR	72538.31	VHAB/MAN	425.59
EXCES KG	0.00	CRUISEKW	2339.27	WHAB/MAN	727.90
RANGE	6000.00	BATTLEKW	1939.09	MEN/DISP	0.05
SUS SHP	40000.00	24 HR KW	1422.24	KWIN/FLD	1.02
END SHP	7831.54	NU LOWSD	0.00	SHP/DISP	10.23
VSUS	29.75	NU MEDSD	4.00		
VEND	20.00	NU HI SD	0.00		
AVSEASPD	27.26	NU GT GN	0.00		
NU ACCOM	190.00	NU ST GN	0.00		
KW INST	4000.00	KW/DIESL	1000.00		
KW SPSER	4000.00	KW/GAS T	0.00		
KW EMERG	0.00	KW/STM G	0.00		

PROPULSION PLANT: RECOMPRESSION ENGINE

FUEL REQUIRED: 663.6 TONS

LBP	410.00	DISP FLD	3841.42	FLD DENS	20.81
BEAM	41.59	DISP LSP	2770.40	LSP DENS	15.01
DRAFT	16.62	VR LOADS	793.98	WPAY/FLD	0.11
D 0	43.77	WT MARG	277.04	WPER/FLD	0.04
D 10	32.00	WTGRP 1	1164.62	WOPS/FLD	0.42
D 20	32.41	WTGRP 2	555.50	VPAY/VOL	0.18
D AVG	34.03	WTGRP 3	150.05	VPER/VOL	0.22
LEN R DK	0.00	WTGRP 4	221.27	VOPS/VOL	0.60
CP	0.60	WTGRP 5	316.59	WTG2/SHP	31.11
CX	0.78	WTGRP 6	226.81	VMB/SHP	2.95
VCG FLD	16.54	WTGRP 7	135.57	WT3/KWIN	84.03
VCG/DAVG	0.49	VOL TOT	413401.60	WTG1/VOL	6.31
L/B	9.86	VOL HULL	349200.40	WTG5/VOL	1.72
B/H	2.50	VOL SSTR	64201.19	VHAB/MAN	425.59
EXCES KG	0.00	CRUISEKW	2318.48	WHAB/MAN	727.94
RANGE	4500.00	BATTLEKW	1924.45	MEN/DISP	0.05
SUS SHP	40000.00	24 HR KW	1404.45	KWIN/FLD	1.04
END SHP	7737.54	NU LOWSD	0.00	SHP/DISP	10.41
VSUS	29.90	NU MEDSD	4.00		
VEND	20.00	NU HI SD	0.00		
AVSEASPD	27.34	NU GT GN	0.00		
NU ACCOM	190.00	NU ST GN	0.00		
KW INST	4000.00	KW/DIESL	1000.00		
KW SPSER	4000.00	KW/GAS T	0.00		
KW EMERG	0.00	KW/STM G	0.00		

PROPULSION PLANT: RECOMPRESSION ENGINE (MODIFIED)

FUEL REQUIRED: 495.1 TONS

LBP	410.00	DISP FLD	3954.49	FLD DENS	21.22
BEAM	41.88	DISP LSP	2807.63	LSP DENS	15.07
DRAFT	17.00	VR LOADS	866.10	WPAY/FLD	0.11
D 0	44.53	WT MARG	280.76	WPER/FLD	0.03
D 10	32.23	WTGRP 1	1191.97	WOPS/FLD	0.43
D 20	32.64	WTGRP 2	556.64	VPAY/VOL	0.18
D AVG	34.35	WTGRP 3	150.89	VPER/VOL	0.22
LEN R DK	0.00	WTGRP 4	221.87	VOPS/VOL	0.60
CP	0.60	WTGRP 5	321.90	WTG2/SHP	31.17
CX	0.78	WTGRP 6	228.80	VMB/SHP	2.96
VCG FLD	16.53	WTGRP 7	135.57	WT3/KWIN	84.50
VCG/DAVG	0.48	VOL TOT	417444.60	WTG1/VOL	6.40
L/B	9.79	VOL HULL	353250.20	WTG5/VOL	1.73
B/H	2.46	VOL SSTR	64194.38	VHAB/MAN	425.59
EXCES KG	0.00	CRUISEKW	2353.76	WHAB/MAN	727.88
RANGE	5000.00	BATTLEKW	1949.15	MEN/DISP	0.05
SUS SHP	40000.00	24 HR KW	1434.55	KWIN/FLD	1.01
END SHP	7911.59	NU LOWSD	0.00	SHP/DISP	10.12
VSUS	29.65	NU MEDSD	4.00		
VEND	20.00	NU HI SD	0.00		
AVSEASPD	27.19	NU GT GN	0.00		
NU ACCOM	190.00	NU ST GN	0.00		
KW INST	4000.00	KW/DIESL	1000.00		
KW SPSER	4000.00	KW/GAS T	0.00		
KW EMERG	0.00	KW/STM G	0.00		

PROPULSION PLANT: RECOMPRESSION ENGINE (MODIFIED)

FUEL REQUIRED: 555.5 TONS

LBP	410.00	DISP FLD	4065.74	FLD DENS	21.62
BEAM	42.09	DISP LSP	2842.23	LSP DENS	15.11
DRAFT	17.39	VR LOADS	939.28	WPAY/FLD	0.11
D 0	45.31	WT MARG	284.22	WPER/FLD	0.03
D 10	33.01	WTGRP 1	1216.28	WOPS/FLD	0.44
D 20	33.42	WTGRP 2	557.80	VPAY/VOL	0.18
D AVG	35.13	WTGRP 3	151.69	VPER/VOL	0.22
LEN R DK	0.00	WTGRP 4	222.46	VOPS/VOL	0.61
CP	0.60	WTGRP 5	327.26	WTG2/SHP	31.24
CX	0.78	WTGRP 6	231.16	VMB/SHP	2.95
VCG FLD	16.66	WTGRP 7	135.57	WT3/KWIN	84.95
VCG/DAVG	0.47	VOL TOT	421338.80	WTG1/VOL	6.47
L/B	9.74	VOL HULL	363164.80	WTG5/VOL	1.74
B/H	2.42	VOL SSTR	58174.06	VHAB/MAN	425.59
EXCES KG	0.00	CRUISEKW	2388.20	WHAB/MAN	727.83
RANGE	5500.00	BATTLEKW	1973.22	MEN/DISP	0.05
SUS SHP	40000.00	24 HR KW	1464.00	KWIN/FLD	0.98
END SHP	8072.30	NU LOWSD	0.00	SHP/DISP	9.84
VSUS	29.40	NU MEDSD	4.00		
VEND	20.00	NU HI SD	0.00		
AVSEASPD	27.03	NU GT GN	0.00		
NU ACCOM	190.00	NU ST GN	0.00		
KW INST	4000.00	KW/DIESL	1000.00		
KW SPSFR	4000.00	KW/GAS T	0.00		
KW EMERG	0.00	KW/STM G	0.00		

PROPULSION PLANT: RECOMPRESSION ENGINE (MODIFIED)

FUEL REQUIRED: 616.7 TONS

LBP	410.00	DISP FLD	4187.67	FLD DENS	21.88
BEAM	42.40	DISP LSP	2884.52	LSP DENS	15.07
DRAFT	17.76	VR LOADS	1014.69	WPAY/FLD	0.10
D 0	46.06	WT MARG	288.45	WPER/FLD	0.03
D 10	33.76	WTGRP 1	1245.35	WOPS/FLD	0.45
D 20	34.17	WTGRP 2	559.00	VPAY/VOL	0.17
D AVG	35.87	WTGRP 3	153.22	VPER/VOL	0.21
LEN R DK	0.00	WTGRP 4	223.25	VOPS/VOL	0.61
CP	0.60	WTGRP 5	333.69	WTG2/SHP	31.30
CX	0.78	WTGRP 6	234.45	VMB/SHP	2.96
VCG FLD	16.80	WTGRP 7	135.57	WT3/KWIN	85.80
VCG/DAVG	0.47	VOL TOT	428706.80	WTG1/VOL	6.51
L/B	9.67	VOL HULL	373570.00	WTG5/VOL	1.74
B/H	2.39	VOL SSTR	55136.79	VHAB/MAN	425.59
EXCES KG	0.00	CRUISEKW	2424.38	WHAB/MAN	727.77
RANGE	6000.00	BATTLEKW	1998.54	MEN/DISP	0.05
SUS SHP	40000.00	24 HR KW	1494.92	KWIN/FLD	0.96
END SHP	8242.17	NU LOWSD	0.00	SHP/DISP	9.55
VSUS	29.15	NU MEDSD	4.00		
VEND	20.00	NU HI SD	0.00		
AVSEASPD	25.88	NU GT GN	0.00		
NU ACCOM	190.00	NU ST GN	0.00		
KW INST	4000.00	KW/DIESL	1000.00		
KW SPSER	4000.00	KW/GAS T	0.00		
KW EMERG	0.00	KW/STM G	0.00		

PROPULSION PLANT: RECOMPRESSION ENGINE (MODIFIED)

FUEL REQUIRED: 679.5 TONS

LBP	410.00	DISP FLD	3295.88	FLD DENS	20.82
BEAM	38.54	DISP LSP	2156.19	LSP DENS	13.62
DRAFT	15.39	VR LOADS	924.08	WPAY/FLD	0.13
D 0	41.30	WT MARG	215.62	WPER/FLD	0.04
D 10	29.00	WTGRP 1	999.99	WOPS/FLD	0.40
D 20	29.41	WTGRP 2	193.19	VPAY/VOL	0.21
D AVG	31.12	WTGRP 3	120.96	VPER/VOL	0.26
LEN R DK	0.00	WTGRP 4	216.31	VOPS/VOL	0.53
CP	0.60	WTGRP 5	285.25	WTG2/SHP	17.29
CX	0.78	WTGRP 6	204.92	VMB/SHP	2.38
VCG FLD	15.29	WTGRP 7	135.57	WT3/KWIN	90.31
VCG/DAVG	0.49	VOL TOT	354585.60	WTG1/VOL	6.32
L/B	10.64	VOL HULL	294577.80	WTG5/VOL	1.80
B/H	2.50	VOL SSTR	60007.81	VHAB/MAN	425.59
EXCES KG	0.00	CRUISEKW	2124.21	WHAB/MAN	728.24
RANGE	4500.00	BATTLEKW	1775.24	MEN/DISP	0.06
SUS SHP	25025.80	24 HR KW	1242.97	KWIN/FLD	0.91
END SHP	6840.88	NU LOWSD	0.00	SHP/DISP	7.59
VSUS	28.00	NU MEDSD	4.00		
VEND	20.00	NU HI SD	0.00		
AVSEASPD	25.76	NU GT GN	0.00		
NU ACCOM	190.00	NU ST GN	0.00		
KW INST	3000.00	KW/DIESL	750.00		
KW SPSER	3000.00	KW/GAS T	0.00		
KW EMERG	0.00	KW/STM G	0.00		

PROPULSION PLANT: GAS TURBINE

FUEL REQUIRED: 634.6 TONS

LBP	410.00	DISP FLD	3504.81	FLD DENS	20.17
BEAM	39.70	DISP LSP	2327.00	LSP DENS	13.39
DRAFT	15.85	VR LOADS	945.11	WPAY/FLD	0.12
D 0	42.22	WT MARG	232.70	WPER/FLD	0.04
D 10	29.92	WTGRP 1	1076.40	WOPS/FLD	0.41
D 20	30.33	WTGRP 2	249.96	VPAY/VOL	0.19
D AVG	32.04	WTGRP 3	125.79	VPER/VOL	0.23
LEN R DK	0.00	WTGRP 4	218.81	VOPS/VOL	0.58
CP	0.60	WTGRP 5	304.44	WTG2/SHP	15.57
CX	0.78	WTGRP 6	216.03	VMB/SHP	2.32
VCG FLD	15.72	WTGRP 7	135.57	WT3/KWIN	93.92
VCG/DAVG	0.49	VOL TOT	389161.50	WTG1/VOL	6.20
L/B	10.33	VOL HULL	312377.60	WTG5/VOL	1.75
B/H	2.50	VOL SSTR	76783.94	VHAB/MAN	425.59
EXCES KG	0.00	CRUISEKW	2205.33	WHAB/MAN	728.12
RANGE	4500.00	BATTLEKW	1842.00	MEN/DISP	0.05
SUS SHP	35962.80	24 HR KW	1308.92	KWIN/FLD	0.86
END SHP	7169.00	NU LOWSD	0.00	SHP/DISP	10.26
VSUS	30.00	NU MEDSD	4.00		
VEND	20.00	NU HI SD	0.00		
AVSEASPD	27.35	NU GT GN	0.00		
NU ACCOM	190.00	NU ST GN	0.00		
KW INST	3000.00	KW/DIESL	750.00		
KW SPSER	3000.00	KW/GAS T	0.00		
KW EMERG	0.00	KW/STM G	0.00		

PROPULSION PLANT: GAS TURBINE

FUEL REQUIRED: 651.5 TONS

LBP	410.00	DISP FLD	3869.86	FLD DENS	19.46
BEAM	41.66	DISP LSP	2625.53	LSP DENS	13.20
DRAFT	16.70	VR LOADS	981.78	WPAY/FLD	0.11
D 0	43.93	WT MARG	262.55	WPER/FLD	0.04
D 10	31.63	WTGRP 1	1207.71	WOPS/FLD	0.42
D 20	32.04	WTGRP 2	332.28	VPAY/VOL	0.17
D AVG	33.75	WTGRP 3	156.70	VPER/VOL	0.20
LEN R DK	0.00	WTGRP 4	223.04	VOPS/VOL	0.63
CP	0.60	WTGRP 5	335.55	WTG2/SHP	14.53
CX	0.78	WTGRP 6	234.69	VMB/SHP	2.37
VCG FLD	16.47	WTGRP 7	135.57	WT3/KWIN	87.75
VCG/DAVG	0.49	VOL TOT	445541.30	WTG1/VOL	6.07
L/B	9.84	VOL HULL	345322.10	WTG5/VOL	1.69
B/H	2.49	VOL SSTR	100219.20	VHAB/MAN	425.59
EXCES KG	0.00	CRUISEKW	2345.35	WHAB/MAN	727.92
RANGE	4500.00	BATTLEKW	1953.29	MEN/DISP	0.05
SUS SHP	51219.27	24 HR KW	1424.21	KWIN/FLD	1.03
END SHP	7775.18	NU LOWSD	0.00	SHP/DISP	13.24
VSUS	32.00	NU MEDSD	4.00		
VEND	20.00	NU HI SD	0.00		
AVSEASPD	28.99	NU GT GN	0.00		
NU ACCOM	190.00	NU ST GN	0.00		
KW INST	4000.00	KW/DIESL	1000.00		
KW SPSER	4000.00	KW/GAS T	0.00		
KW EMERG	0.00	KW/STM G	0.00		

PROPULSION PLANT: GAS TURBINE

FUEL REQUIRED: 681.4 TONS

LBP	410.00	DISP FLD	3291.77	FLD DENS	18.26
BEAM	40.77	DISP LSP	2281.85	LSP DENS	12.66
DRAFT	14.48	VR LOADS	781.74	WPAY/FLD	0.13
D 0	39.46	WT MARG	228.18	WPER/FLD	0.04
D 10	32.00	WTGRP 1	1029.53	WOPS/FLD	0.39
D 20	32.41	WTGRP 2	261.56	VPAY/VOL	0.19
D AVG	33.31	WTGRP 3	120.72	VPER/VOL	0.23
LEN R DK	0.00	WTGRP 4	218.83	VOPS/VOL	0.58
CP	0.60	WTGRP 5	294.64	WTG2/SHP	23.27
CX	0.78	WTGRP 6	220.98	VMB/SHP	4.18
VCG FLD	16.35	WTGRP 7	135.57	WT3/KWIN	90.14
VCG/DAVG	0.49	VOL TOT	403793.10	WTG1/VOL	5.71
L/B	10.06	VOL HULL	348656.40	WTG5/VOL	1.63
B/H	2.82	VOL SSTR	55136.79	VHAB/MAN	425.59
EXCES KG	0.00	CRUISEKW	2119.67	WHAB/MAN	728.25
RANGE	4500.00	BATTLEKW	1772.66	MEN/DISP	0.06
SUS SHP	25174.53	24 HR KW	1239.67	KWIN/FLD	0.91
END SHP	6973.37	NU LOWSD	0.00	SHP/DISP	7.65
VSUS	28.00	NU MEDSD	4.00		
VEND	20.00	NU HI SD	0.00		
AVSEASPD	25.62	NU GT GN	0.00		
NU ACCOM	190.00	NU ST GN	0.00		
KW INST	3000.00	KW/DIESL	750.00		
KW SPSER	3000.00	KW/GAS T	0.00		
KW EMERG	0.00	KW/STM G	0.00		

PROPULSION PLANT: FEHER BASIC ENGINE

FUEL REQUIRED: 492.5 TONS

LPP	410.00	DISP FLD	3343.43	FLD DENS	18.31
BEAM	40.94	DISP LSP	2324.07	LSP DENS	12.87
DRAFT	14.69	VR LOADS	786.96	WPAY/FLD	0.13
D 0	39.89	WT MARG	232.41	WPER/FLD	0.24
D 10	32.00	WTGRP 1	1045.58	WCPS/FLD	0.39
D 20	32.41	WTGRP 2	280.69	VPAY/VOL	0.19
D AVG	33.38	WTGRP 3	120.87	VPER/VOL	0.23
LIN R DK	0.00	WTGRP 4	219.09	VOPS/VOL	0.58
CP	0.60	WTGRP 5	300.69	WTG2/SHP	18.29
CX	0.78	WTGRP 6	221.58	VMB/SHP	3.06
VCG FLD	16.40	WTGRP 7	135.57	WT3/KWIN	90.25
VCG/DAVG	0.49	VOL TOT	404514.10	WTG1/VOL	5.79
L/B	10.01	VOL HULL	349377.30	WTG5/VOL	1.67
B/H	2.79	VOL SSTR	55136.79	VHAB/MAN	425.59
EXCES KG	0.00	CRUISEKW	2154.88	WHAB/MAN	728.32
RANGE	4500.00	BATTLEKW	1805.42	MEN/DISP	0.06
SUS SHP	34368.75	24 HR KW	1266.68	KWIN/FLD	0.90
END SHP	7057.64	NU LOWSD	0.00	SHP/DISP	10.28
VSUS	30.00	NU MEDSD	4.00		
VEND	20.00	NU HI SD	0.00		
AVSEASPD	27.20	NU GT GN	0.00		
NU ACCOM	190.00	NU ST GN	0.00		
KW INST	3000.00	KW/DIESL	750.00		
KW SPSER	3000.00	KW/GAS T	0.00		
KW EMERG	0.00	KW/STM G	0.00		

PROPULSION PLANT: FEHER BASIC ENGINE

FUEL REQUIRED: 495.7 TONS

LBP	410.00	DISP FLD	3389.65	FLD DENS	18.73
BEAM	41.09	DISP LSP	2362.41	LSP DENS	13.06
DRAFT	14.84	VP LOADS	791.00	WPAY/FLD	0.13
D C	40.19	WT MARG	236.24	WPER/FLD	0.04
D 10	32.00	WTGRP 1	1059.23	WCPS/FLD	0.39
D 20	32.41	WTGRP 2	299.76	VPAY/VOL	0.19
D AVG	33.43	WTGRP 3	121.03	VPER/VOL	0.23
LEN P DK	0.00	WTGRP 4	219.29	VOPS/VOL	0.59
CP	0.60	WTGRP 5	306.41	WTG2/SHP	15.41
CX	0.78	WTGRP 6	222.12	VMB/SHP	2.42
VCG FLD	16.45	WTGRP 7	135.57	WT3/KWIN	90.37
VCG/DAVG	0.49	VOL TOT	405311.10	WTG1/VOL	5.85
L/B	9.98	VOL HULL	350174.30	WTG5/VOL	1.69
B/H	2.77	VOL SSTR	55136.79	VHAB/MAN	425.59
EXCES KG	0.00	CRUISEKW	2185.29	WHAB/MAN	728.19
RANGE	4500.00	BATTLEKW	1834.91	MEN/DISP	0.06
SUS SHP	43563.48	24 HR KW	1289.57	KWIN/FLD	0.89
END SHP	7122.76	NU LOWSD	0.00	SHP/DISP	12.85
VSUS	32.00	NU MEDSD	4.00		
VEND	20.00	NU HI SD	0.00		
AVSEASPD	28.79	NU GT GN	0.00		
NU ACCOM	190.00	NU ST GN	0.00		
KW INST	3000.00	KW/DIESL	750.00		
KW SPSER	3000.00	KW/GAS T	0.00		
KW EMERG	0.00	KW/STM G	0.00		

PROPULSION PLANT: FEHER BASIC ENGINE

FUEL REQUIRED: 498.2 TONS

Thesis
C6573 Combs 170588
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